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Alternatives for Hazardous Waste Management in the Petroleum Refining Industry

Jacobs Engineering Co.
Pasadena, CA

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1979

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ALTERNATIVES FOR HAZARDOUS WASTE MANAGEMENT IN THE PETROLEUM REFINING INDUSTRY

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U.S. ENVIRONMENTAL PROTECTION AGENCY
1979

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The overall objective of this study was to assess the alteratives to land disposal for treatment and disposal of potentially-hazardous wastes generated by petroleum refining industry.

The aim of this project was to identify promising resource recovery and detoxification oriented treatment techniques which are applicable to these wastes.

This study provides:

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ABSTRACT

This report identifies and evaluates technology to recover oil from waste sludges in the petroleum refining industry. The waste sludges are characterized to determine the composition of the waste streams. The study reveals that oil is the significant potentially hazardous substance and metals present in all but one stream occur in small quantities and in a stable form. A phase separation system utilizing acetone as the solvent was selected for recovery of oil. The system can recover up to 95 percent of the oil for reuse and achieves 80 percent volume reduction. The estimated capital cost for the system is $1,512,000, the operation and maintenance costs are $232,000/year, energy costs $153,300/year and value of benefits derived is $451,000/year. The net annual costs after amortization of capital @ 10 percent over 10 years are $180,000. The product cost impact is 1.5¢/cu m (0.24¢/bbl). The proposed system is conceptual and has not been tested on bench scale or pilot plant studies. To compare costs of the phase separation system with incineration and land disposal, detailed cost estimates are developed for incineration, sanitary landfill and chemical landfill for the same waste sludges.

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1.0 EXECUTIVE SUMMARY

Introduction

This report is a result of a study commissioned by the Office of Solid Waste (OSW) to assess the alternatives to incineration and land disposal for the 17 potentially hazardous waste streams from petroleum refining operations identified in the previously completed industry study (1). The alternatives to be analyzed include unit processes and combinations of unit processes identified in a report entitled "Physical, Chemical and Biological Treatment Techniques for Industrial Wastes," which was prepared for the Environmental Protection Agency (EPA) by A. D. Little, Inc. (2)

The primary objective of this study is to identify technology for the candidate waste streams which may achieve materials or energy recovery, accomplish detoxification or immobilization, and reduce the volume of waste for ultimate disposal. The need for recovery of usable resources and energy is a major consideration in the current worldwide situation. This report develops a number of conceptual alternatives for treatment of the 17 potentially hazardous waste streams and identifies research, development and demonstration needs for treatment operations having a high potential for better waste management. A complete cost analysis is carried out for each proposed system to include capital costs, operation and maintenance costs, energy costs, and value of benefits derived.

Methodology

Jacobs Engineering Co. (JEC) utilized various approaches to attain the objectives of this study, such as a matrix comparison of waste streams with unit processes, consultations with technology consultants, and meetings with the American Petroleum Institute (API). JEC carried out additional characterization of the 17 waste streams to determine the nature of the potentially hazardous substances present in the waste streams. This research was of particular significance since the earlier industry study (1) had only indicated the various elements, such as nickel, arsenic, mercury, but did not specify in what form they occurred; i.e., oxide, silicate or carbonate. The results of this additional characterization, based on engineering judgment and expertise, revealed four significant facts.

(1) Oil is the significant potentially hazardous substance present in 15 of the 17 waste streams.

(2) Metals present in 16 of the 17 waste streams occur in small quantities and in a stable form, i.e., not readily leachable and not releasing toxic fumes on incineration.

(3) HF alkylation sludge contains, besides oil, various toxic metals in a readily leachable form and releases toxic fumes on incineration.

(4) Two of the 17 waste streams, coke fines and FCC catalyst fines, do not pose an environmental hazard, since they are products of high temperature combustion and contain all potentially hazardous substances in a stable form.

To determine the potential for recovery of materials and energy, JEC carried out a comprehensive evaluation of the total market value of all materials in the 17 waste streams. The results of this evaluation indicate that the total value of all metals in the 17 waste streams is less than $30/day for a modern refinery (32,000 cu m/day or 200,000 bbl/day) and hence does not justify resource recovery. The available quantity of oil in the waste streams is valued at about $1,000/day.

Based on the above findings, it became clear that recovery of oil from the waste streams would simultaneously achieve the recovery of energy or resources from and detoxification of 14 of the 15 waste streams posing an environmental hazard. HF alkylation sludge has to be additionally processed for precipitation of dissolved metals.

Process Selection

JEC has selected three distinct systems based on the characteristics of the waste streams. Streams 1 through 10 listed below contain significant quantities of oil, and hence are subjected to a phase separation system to recover oil.

1. Slop Oil Emulsion Solids
2. Silt From Storm Water Runoff
3. Exchanger Bundle Cleaning Sludge
4. API Separator Sludge
5. Nonleaded Tank Bottoms
6. Crude Tank Bottoms
7. Leaded Tank Bottoms
8. Dissolved Air Floatation Skimmings
9. Kerosene Filter Clays
10. Lube Oil Filter Clays

Stream 11, HF alkylation sludge, goes through a phase separation system, followed by a lime precipitation system to remove dissolved metals. Streams 12 through 15 listed below contain small quantities of oil (less than 3%), and are therefore not suitable for an oil recovery process and are subjected to a calcination system to burn the residual oil and convert any potentially hazardous substances to a stable form.

12. Spent Lime from Boiler Feedwater
13. Waste Bio Sludge
14. Once Through Cooling Water Sludge
15. Cooling Tower Sludge

Phase Separation System

JEC made a complete review of commercially available solvents for extraction of oil and water from waste sludges. Acetone was selected as the solvent of choice for the phase separation system for two primary reasons. First, it has the unique ability to dissolve significant quantities of both oil and water. Second, acetone does not form azeotropes with either oil or water, which permits recovery of high purity acetone for reuse.

The proposed phase separation system is conceptual and has not been tested either in bench scale studies or pilot plant tests. The system consists of holding tanks, centrifuge, rotary drier, acetone absorption column, acetone recovery column and decantation tank. To keep the system to minimum size and optimum performance, the processing is carried out on a continuous basis. The proposed system recovers better than 95 percent of the oil for reuse, achieves an impressive 80 percent volume reduction and substantial savings in disposal costs.

The capital cost for the system is $1,512,000, the operation and maintenance costs are $232,000/year, energy costs $153,300/year and value of benefits derived is $451,500/year. The net annual costs after amortization of capital @ 10 percent over 10 years are $180,000. The product cost impact is 1.5 cents/cu m (0.2 cents/bbl). The system does not pose any serious environmental or safety concerns. The proposed phase separation system is purely conceptual and must be developed further in terms of technical feasibility, engineering design, specifications, and pilot plant work.

HF Alkylation Sludge

JEC has designed a separate system for HF alkylation sludge which includes precipitation of the dissolved metals as their hydroxides, after recovery of oil by phase separation. The total annual costs for the system, including oil recovery is $40,000. The product cost of the system is 0.1 cent/ cu m.

Calcination System

Waste streams 12 through 15 identified earlier containing residual amounts of oil and other potentially hazardous substances are subjected to the calcination system. The calcination process concentrates the wastes, destroys organic matter, and leaves inorganic compounds in an acceptable form for landfill. The system consists of a slurry feed tank, centrifuge, rotary kiln, calciner, cyclone and wet scrubber. The capital costs for the system are $600,000, the operation and maintenance costs are $144,000/year and energy costs are $41,000/yr. The net annual costs after amortization of capital at 10 percent over 10 years is $445,000. The product cost impact of this system is 1.9 cents/cu m (.03 cents/bbl).

Cost Comparison On Both Wet and Dry Weights

To compare costs of the recommended systems with incineration and land disposal, Jacobs developed detailed cost estimates for incineration, sanitary landfill and chemical landfill. Tables 1-1 and 1-2 provide a complete summary of treatment costs for recommended systems vs. incineration and landfill disposal.

For waste streams 1 through 10, the phase separation system costs $6.90 per metric ton compared to $5.39 for sanitary landfill, $16.34 for chemical landfill and $5.50 for incineration. The product cost impact for the phase separation system is 1.5 cents/cu m (0.2 cent/bbl).

For waste stream 11, HF alkylation sludge, treatment system costs are $48.20 per metric ton compared to $16.31 per metric ton for chemical landfill. The product cost impact is 0.1 cent/cu m.

For waste streams 12 through 15 the calcination system costs $11.93 per metric ton compared to $5.39 per metric ton for sanitary landfill, $16.01 per metric ton for chemical landfill and $14.20 for incineration. The product cost impact for the calcination system is 1.9 cents/cu m, (0.3 cent/bbl).

TABLE 1-1

ALTERNATIVE TREATMENT COST SUMMARY

Waste Stream	Alternative Treatment Process[3] Train #1			Benefits Derived	Total Treatment Cost ($/MT[2])		Product Cost Impact[1]
	Unit Process	Nature	Stage of Development		Wet Basis	Dry Basis	
Streams 1 thru 10	Solvent Extraction	Chemical	IV				
	Centrifugation	Physical	V				
	Decantation	Physical	V	Oil Recovery Volume Reduction	$ 6.90	$ 36.13	1.5 cents/cu m
	Drying	Physical	V				
	Condensation	Physical	IV				
	Steam Stripping	Physical	IV				
Stream 11	All-unit processes above, plus:						
	Precipitation	Chemical	V				
	Flocculation	Chemical	V				
	Sedimentation	Physical	V	Detoxification Volume Reduction	$48.20	$123.98	0.3 cent/cu m
	Filtration	Physical	V				
	Decantation	Physical	V				
Streams 12 thru 15	Pretreatment (polymer addition with mixing)	Chemical	V				
	Centrifugation	Physical	V				
	Mechanical Separation	Physical	V	Volume Reduction Detoxification	$11.93	$26.59	1.9 cents/cu m
	Calcination	Chemical	IV				
	Absorbtion	Physical	IV				

1) Crude oil processing capacity of 32,000 cu m/day (200,000 bbl/day). One mill is 1/10th of a cent.

2) MT - metric ton.

3) Unit processes in the same order as recommended for treatment.

4) IV - Developed but not commonly used in waste treatment.
   V - Commonly used in waste treatmetn.

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TABLE 1-2
COMPARATIVE COST SUMMARY

Waste Stream	Sanitary Landfill			Chemical Landfill			Incineration(1)		
	Total Disposal Cost $/MT		Product(1) Cost Impact	Total Disposal Cost $/MT		Product(1) Cost Impact	Total Cost $/MT		Product(1) Cost Impact
	Wet Basis	Dry Basis		Wet Basis	Dry Basis		Wet Basis	Dry Basis	
Streams 1 Thru 10(2)	5.39	28,23	1.2¢/cu m	16.54	86.61	3.6¢/cu m	5.50	29.77	1.2¢/cu m
Stream 11	NA	NA	NA	16.31	41.95	NA	NA	NA	NA
Streams 12 Thru 15	5.39	11.58	0.9¢/cu m	16,01	34.38	2.7¢/cu m	14.20	31.55	2.3¢/cu m
			3.1¢/cu m			6.4¢/cu m			3.5¢/cu m

Notes:

1) Crude oil processing capacity of 32,000 cu m/day (200,000 bbl/day). Mill is 1/10 of a cent, 7 mills/cu m corresponds to 1 mill/bbl.

2) Land farming is the prevalent practice for disposal of these waste streams.

3) NA - Not applicable since the waste stream contains readily leachable constituents as well as constituents that release fumes.

Implementation of all recommended systems for waste streams 1 through 15 will produce a total product cost impact of 3.7 cents/cu m (0.5 cent/bbl) for a 32,000 cu m/day refinery, (200,000 bbl/day).

This report contains a large number of cost elements and hence requires proper perspective prior to making any conclusions. The treatment and/or disposal costs per metric ton of waste includes the value of benefits derived, hence it is not directly comparable to similar cost figures for another industry. Similarly, the product cost impact is based on crude oil processing capacity and not the actual costs for refining a cubic meter of crude oil. For example, gasoline selling at 60¢/gallon at the pump includes only about 10¢/gallon for refining costs.

Existing Installations

Based on literature search, meetings with technology consultants and industry survey, Jacobs has determined that there are no full-scale operating installations, laboratory or pilot scale facilities in the petroleum refining industry to recover energy or resources on a continuous and systematic manner from the 17 waste streams. It must be noted that the industry does utilize various unit processes to extract and recover oil from certain waste streams such as tank bottoms and API separator skimmings. The industry claims that the quantity of oil available in the waste streams may be significantly lower than those determined in the industry study (1). Hence it is suggested that the oil content of the candidate waste streams be verified prior to finalizing the treatment concept.

2.0 PURPOSE AND APPROACH FOR THE STUDY

2.1 Purpose of the Study

The Office of Solid Waste (OSW) has completed a study on "Assessment of Hazardous Waste Practices in the Petroleum Refining Industry,"(1) called the "Industry Study." This study identified the various sources of potentially hazardous wastes from the petroleum refining operations and identified the current technology for their disposal; which, in most cases, was land disposal or incineration. The purpose of this study is to assess the alternatives to land disposal and incineration for those waste streams which have been identified in the previous study. The alternatives to be analyzed were the unit process or combination of unit processes identified in a report titled "Physical, Chemical and Biological Treatment Techniques for Industrial Wastes" prepared by Arthur D. Little under a contract from EPA (2) called the "Treatment Study."

A major purpose of this "alternative study" is to identify treatment techniques for potentially hazardous wastes which may facilitate materials or energy recovery, accomplish waste detoxification, or immobilization, or which may reduce the volume of waste for ultimate disposal. The primary purpose of this study is to identify promising resource recovery and detoxification techniques. A complete cost analysis of the proposed systems has to be carried out to include capital costs, operation and maintenance costs, energy costs and value of benefits to be derived. These system costs are to be compared with costs of disposal by incineration, sanitary landfill, and chemical landfill.

2.2 An Approach for the Study

As a first step, Jacobs Engineering Co. (JEC) prepared a matrix with the 17 waste streams and 44 unit processes to determine which of the unit processes are appropriate for each waste stream (Appendix A). By eliminating those unit processes with characteristics not suitable for specific waste streams, the choice of unit processes was narrowed down to a more manageable number.

As a next step, JEC met with EPA technology consultants to review the preliminary selection of applicable unit processes and to develop additional ideas based on their expertise. These meetings were held twice with various experts from the technology consultants, Arthur D. Little, Inc. Further information was compiled during literature reviews and meeting with the Solid Waste Management Committee of the American Petroleum Institute (API).

Early in the study, JEC realized that the "Industry Study" (1) did not specify the nature of the potentially hazardous substances in the waste streams. It was deemed necessary to further characterize the 17 waste streams prior to selection of unit processes. In addition to determing the nature and quantity of recoverable materials and energy, JEC carried out a potential market value analysis of all marketable elements present in the 17 waste streams.

Analyses mentioned above were utilized for selection of unit processes and systems to recover materials and energy from the candidate waste streams from a typical 32,000 cu m/day (200,000 bbl/day) refinery. A complete cost analysis is carried out for the selected systems for similar groups of waste streams.

JEC realizes that the 17 waste streams all have certain unique properties, but in a real-world situation, similar waste streams will be combined prior to treatment. Hence, JEC has combined the 17 waste streams into four groups based on the quantity of recoverable oil and hence energy in each of the waste streams.

2.3 Selection of a Refinery

It is necessary to determine what production size ranges are found in the petroleum refining industry to prepare cost estimates for the appropriate refinery. The industry study for the petroleum refining industry (1) categorized the industry into four types based on unit processes as shown in Table 2.1.

The Oil and Gas Journal conducts an annual survey of operating refineries listing crude processing capacity and unit processes for all refineries. According to the current survey (March, 1976) 17 refineries show lube oil production capacity without any of the associated unit processes. These refineries are concentrated in the Pennsylvania-West Virginia area and utilize Penn Grade crude. This type of crude is very high in the lube oil fractions, and requires very little processing. Most of these refineries are very small (less than 10,000 BPSD), and are classified as a Type I refinery based on the absence of unit processes for lube oil processing. Two refineries of a total of 255 do not fit in the above categorization system, but have been included in the nationwide totals. Table 2.2 shows the breakdown of operating United States refineries. Table 2-3 shows U. S. refineries planned or under construction.

TABLE 2-1

CATEGORIZATION OF THE PETROLEUM REFINING INDUSTRY

Refinery Type	Unit Processes
I	Crude Vacuum Distillation, Liquidfied Petroleum Gas Recovery, Hydrotreating, Hydrofining, Reforming, Alkylation, Isomization, Visbreaking
II	All processes included in Type I and Fluid Catcracking and Hydroflowing
III	All processes included in Type II and Fluid or Delayed Coking
IV	All processes included in Type III plus Lube Oil Processing and Petrochemical Facilities

TABLE 2-2

U.S. REFINERY CAPACITY

Refinery Type	I	II	III	IV	Totals (1)
Total Capacity BPSD	1,319,400	5,358,400	3,996,940	5,026,560	15,742,800
Number of Refineries	105	86	38	24	255
Average Capacity BPSD	12,570	60,890	105,180	209,440	61,736
Median Capacity BPSD	6,000	51,000	97,000	190,000	—

TABLE 2-3

U.S. REFINERY PLANNED/UNDER CONSTRUCTION

Refinery Category	Total Additional Crude Capacity Under Construction	No.of Projects	New Refineries
Type I	126,900 BPSD	5	1
Type II	540,030 BPSD	8	3
Type III	414,220 BPSD	3	1
Type IV	884,210 BPSD	5	2

(1) Two refineries of a total of 255 do not fit in the outlined categorization.

The Oil and Gas Journal's annual construction index (October 4, 1976) shows the refinery projects included in Table 2-3 as either planned or under construction. Examination of Table 2-3 indicates that proposed refineries in all four categories are substantially larger than the current averages. Figure 2-1 is a plot of the total U. S. refinery capacity vs. the number of refineries in order of increasing capacity.

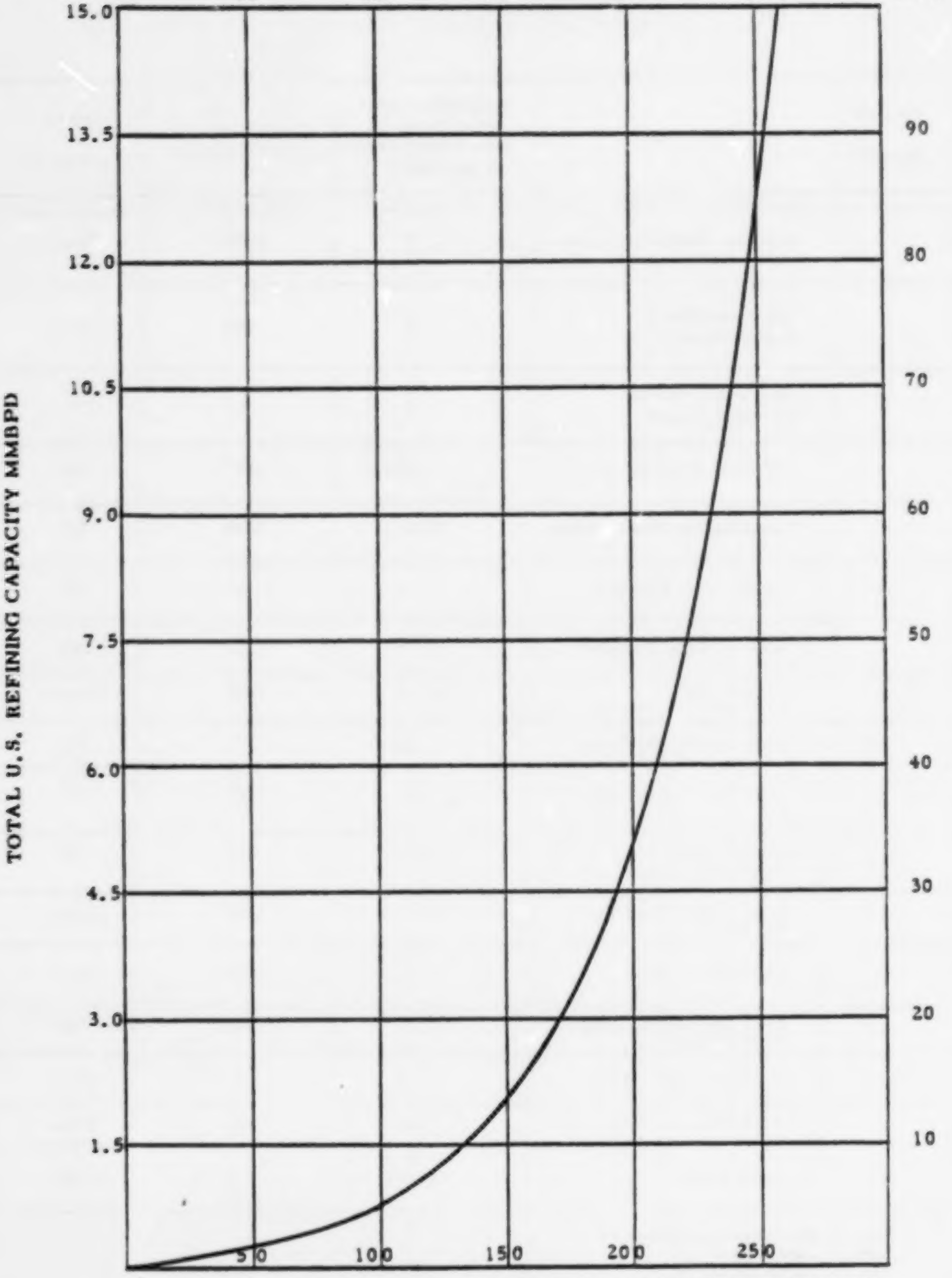
A close examination of Tables 2-2, 2-3, and Figure 2-1 suggests that a large percentage of U. S. refining capacity is accounted for by a small number of refineries with crude oil processing capacity of 200,000 bbl/day or more. Hence, for this study JEC has selected a 32,000 cu m/day, (200,000 BPSD), Type IV modern refinery as being the most appropriate, for purposes of preparing cost estimates for recovery and reuse of potentially hazardous wastes.

2.4 Waste Generation for a 32,000 cu m/day Refinery

It is necessary to know the quantity and composition of the waste streams to select appropriate unit processes for subsequent treatment. To prepare appropriate cost estimates for the various treatment schemes Table 2-4 develops the total waste generation for each stream for the 32,000 cu m/day refinery. The generation rate for each waste stream is based on data in Table 39 of the industry study (1). The methodology and derivation of the generation rate for each waste stream is included in Appendix B. Table 2-4 also includes the method of generation for each waste stream, i.e., batch, continuous or at turnaround.

Table 2-5 outlines the composition of oil, water, and solids in each of the 17 waste streams, based on the percentage breakdown given in Table 39 of the industry study (1). A quick review of Table 2-5 indicates that 6 waste streams contain more than 20% oil by weight and 5 streams contain more than 3% oil by weight. These are selected candidate streams for further processing to recover oil by phase separation. The remaining 6 waste streams have less than 0.5% oil by weight.

The Solid Waste Management Committee of the American Petroleum Institute has pointed out that the oil content in the various waste streams indicated in Table 39 of the industry study may be on the high side. They claim that the industry currently does extract oil from tank bottoms by vari-angle mixers and from API sludges by phase separation in heated vessels. Hence, it is recommended that prior to carrying out pilot plant studies of oil recovery systems, additional



NUMBER OF REFINERIES IN ORDER OF INCREASING CAPACITY
FIGURE 2-1

TABLE 2-4

WASTE GENERATION FROM A TYPICAL REFINERY

32,000 cum/day (200,000 BPSD)

Stream Number	Waste Stream	Generation Rate (Wet Weight) Met Tons/Year/ 1000 BPSD	* (Met Tons/yr) Waste Quantity	Method of Generation
1.	Slop Oil Emulsion Solids	11.5	2300	Cont.
2.	Silt From Storm Water Runoff	2.8	562	BO
3.	Exchanger Bundle Cleaning Sludge	0.9	182	TA
4.	API Separator Sludge	9.02	1803	BO
5.	Non-Leaded Tank Bottoms	25.4	5083	BO
6.	Crude Tank Bottoms	0.14	29	BO
7.	Leaded Tank Bottoms	0.14	29	BO
8.	Dissolved Air Floatation Skimmings	66.15	13230	Cont.
9.	Kerosine Filter Clays	1.02	203	BO
10.	Lube Oil Filter Clays	13.2	2636	BO
11.	Neutralized HF Alkylation Sludge	4.1	823	BO
12.	Spent Lime From Boiler Feedwater	71	14200	Cont.
13.	Waste Bio Sludge	6.3	1258	Cont.
14.	Once Through Cooling Water Sludge	16.9	3380	BO
15.	Cooling Tower Sludge	0.12	24	Cont.
16.	FCC Catalyst Fines	1.86	371	Cont.
17.	Coke Fines	0.008	2	BO

BO - Batch During Operation
Cont. - Continuous
TA - Turnaround

* metric tons

TABLE 2-5

COMPOSITION OF WASTE STREAM FROM A TYPICAL REFINERY
32,000 cu.m/day (200,000 BPSD)

Stream Number	Waste Stream	Total Quantity * Met Tons/yr.	Breakdown Metric Tons/yr.			% Oil in Waste Stream
			Oil	Water	Inerts	
1.	Slop Oil Emulsion Solids	2300	1104	920	276	48
2.	Silt From Storm Water Runoff	562	22	140	400	3.9
3.	Exchanger Bundle Cleaning Sludge	182	20	96	66	10.7
4.	API Separator Sludge	1803	407	956	440	22.6
5.	Non-Leaded Tank Bottoms	5083	3263	900	920	64.2
6.	Crude Tank Bottoms	29	14	4	11	47.4
7.	Leaded Tank Bottoms	29	6	0	23	20.0
8.	Dissolved Air Floatation Skimmings	13230	1650	10850	730	12.5
9.	Kerosine Filter Clays	203	7	10	186	3.5
10.	Lube Oil Filter Clays	2636	577	132	1927	21.9
11.	Neutralized HF Alkylation Sludge	823	57	446	320	6.9
12.	Spent Lime From Boiler Feedwater	14200	45	8378	5777	0.32
13.	Waste Bio Sludge	1258	4	1094	160	0.28
14.	Once Through Cooling Water Sludge	3380	15	845	2520	0.43
15.	Cooling Tower Sludge	24	0	18	6	0.44
16.	FCC Catalyst Fines	371	1	0	370	0.21
17.	Coke Fines	2	0	0	1.6	0

* metric tons/year

data be obtained on the oil content of specific waste streams for 32,000 cu m/day (200,000 bbl/day) or larger refineries.

2.5 Characterization of the Waste Streams

This section describes the origin and characteristics of the various components in order to determine the prevalence of potentially hazardous substances in the 17 waste streams from petroleum refining operations. The industry study (1) identified the various elements but did not indicate the form of occurrence. JEC has made a subjective evaluation of the various components that may be present based on analytical data, engineering judgment, and experience. Appendix C indicated the form of occurrence (like carbonates, oxides, silicates, etc.,) of each component for all 17 waste streams. This section is important to identify the nature of the hazardous substance in each of the 17 waste streams.

Slop Oil Emulsion Solids

Skimmings from the API separator are placed in a storage vessel. The mixture consists of oil, water and skimmings. A major portion of the oil floats on top because of its low density. The surface oil layer is returned to crude storage; the water phase goes to the wastewater treatment system. The intermediate phase, generally a highly emulsified mixture of oil, water, and solids, becomes a waste stream. The composition of the waste stream by weight is typically 40 percent water, 48 percent oil, and 12 percent solids. Chromium and zinc are present in high quantities (525 and 250 ppm) in the solids due to their use in treatment of cooling water. Lead which is present originates from gasoline or in washdown of spills around the tetra ethyl lead (TEL) blender. Other metals are present in amounds similar to that in crude feedstock and/or the refinery's water supply.

Silt From Storm Water Runoff

Drainage during storm flows is typically diverted to a holding basin for release into the refinery wastewater treatment system during off-peak periods. The contents of the holding basin are periodically removed. Contaminants from any phase of the refinery operation that would be exposed to rain water runoff may be present. Metals are insoluble in form. The solids are largely sand or silt from the runoff. The percent compositions of oil, water and solids in the waste stream is 4, 25, and 71 respectively.

Exchanger Bundle Cleaning Sludge

Heat exchanger bundles are cleaned during plant shutdown to remove deposits of scale and sludge. Depending on the characteristics of the deposits, the outside of the tube bundles may be washed, brushed, or sandblasted, while the tube insides can be wiped, brushed, or rodded out. Sludge resulting from the cleaning process has approximately 53 percen water, 11 percent oil and 36 percent of solids.

The solids are insoluble, and are composed largely of silt precipitated from the water. The metals present are mostly corrosion products or scale deposits from the exchanger bundle tubes. Nickel and chromium probably occur as oxides or silicates. The presence of oil results from cleaning of the outside of the bundles or from small leaks in the tubes of the bundle.

API Separator Sludge

The solids which settle in the API separator are periodically removed. Since refinery API separators are usually connected to the oily water plant sewer, the API separator sludge will, therefore, contain a mixture of all sewered wastes, such as tank bottoms, boiler blowdown, desalter wastes, as well as traces of all chemical elements present in the refinery processes.

Oil present will most likely be present as heavy tars because the surface oil skimmed periodically from the API separator. Oil content of the sludge is approximately 23 percent by weight. Water and solids constitute approximately 53 percent and 24 percent respectively. Most of the solids content is silt and sand. Any metals present are insoluble, probably carbonates or hydroxides. Lead results from the presence of TEL. High concentrations (250 mg/l) of chromium resulting from its use as a corrosion inhibitor are likely to be in the form of the hydroxide.

Product Tank Bottoms (Leaded/Nonleaded)

The petroleum products (or fractions) after being separated in the distillation column have to be cooled before they are sent out or used for making other by-products. This is done in product storage tanks. As cooling occurs, the water separates from the hydrocarbon phase and is continually drained from the tanks to the refinery water treatment system. Solids formed as products of corrosion and rust in the tanks are insoluble in nature, and are periodically removed.

Tetra ethyl lead (TEL) is included in most gasolines to raise the octane number and TEL is the principal contributor to the formation of deposits in the tanks.

Crude Tank Bottoms

The sludge formed in crude storage tanks is similar to that in product storage tanks with several exceptions. Its oil content is higher, since it results from storage of an unrefined product. Sand and silt are also present in greater quantities. Metal concentrations depend upon the type of crude used as a feedstock. Insoluble products of rust and corrosion of the storage vessel are also present. The average composition of oil, water and solids of the waste stream are 48 percent, 13 percent, and 39 percent.

DAF Skimmings

Some refineries utilize dissolved air flotation following primary separation in the API to remove additional oil and solids. The process brings finely divided oil and solid particles to the surface where they are skimmed for disposal.

Water typically constitutes 80% - 85% by weight of this waste stream, oil, 10% - 15% and solids 0 - 5%. The solids are generally fine silts which did not have sufficient residence time in the primary separators to settle. Concentrations of trace metals in this waste stream are typically very low.

Kerosene Filter Clays

A clay filter, either bentonite or fuller's earth (both consisting of montmorillonite), is used to remove impurities from highly refined kerosene products. The clay is discarded when it becomes saturated with water and impurities. Very little oil is normally found because the clay is steam cleaned prior to disposal. Most of the metals present in the waste are from the discarded filter clay itself, and those present in toxic amounts are organically bound. The kerosene filter clays contain 5 percent water, 3.5 percent oil and 91.5% solids.

Lube Oil Filter Clays

Lube oils are filtered with the same material which is used to filter kerosene. A higher concentration of oil is found in the waste stream because more oil is present in the material being filtered. A higher concentration of organo-metallic compounds is also present since the refining process concentrates trace metals in the clay bed. The water, oil and solids percentages in lube 0.1 filters clays are 5, 22 and 73 respectively.

Neutralized HF Alkylation Sludge

Catalytic alkylation is utilized to produce high octane components from refinery gas streams. Modern refineries utilize sulfuric acid, which is sold for regeneration after use, however many refineries use hydrofluoric acid as a catalyst. Since the produce absorbs small amounts of HF, product neutralization is required prior to marketing. Material typically used for neutralization is fresh limes.

The neutralized HF sludge will, in general, contain approximately 50 percent water, 5 percent oil and 45 percent solids. The major component of the solids portion will be the $CaCO_3$ precipitate from neutralization. Reaction of the acid water and the $CaCO_3$ forms CaF_2 (about 10 percent wet weight). Other impurities are introduced from two sources--corrosion products from HF alkylation and the sludge precipitated during neutralization. Metals present occur in the form of fluorides. "The fluorides of the common alkali metals and of silver, mercury, aluminum and nickel are readily soluble in water; those of lead, copper, ferric iron, barium and lithium are slightly soluble; and those of the alkaline earth metals are insoluble in water." (3)

Spent Lime

This waste stream is similar to that of any large industrial installation utilizing lime in treatment of boiler feedwater. Solids compose approximately 40% of this waste stream, and occur mostly as insoluble metallic precipitates, of carbonates or hydroxides the remainder being water (59 percent) and small quantity of oil (less than 0.5 percent).

Waste Biosludge

Biosludge is generated by refineries which utilize biological treatment of wastewater streams. The waste biosludge has very high water content (99%) and is generally dewatered to about 15% solids before disposal.

Once-Through Cooling Water Sludge

Once-through cooling water is passed through primary settling tanks prior to usage. Periodic cleaning of the holding tanks generates this waste stream. Solids are usually silt from the source water (typically a river) and constitutes 74.5 percent of the waste. The metals present are in an insoluble form. Only trace amounts of oil (less than 0.5 percent) are generally present in this waste stream. The weight percent of water in the waste stream is 25 percent.

Cooling Tower Sludge

Sludge which settles in the cooling tower is removed whenever the cooling tower is not in operation. Oil, water and sludge typically compose 0.5 percent, 75.5 percent and 24 percent of this waste stream. Metals present are in an insoluble form, either carbonates or oxides. Chromium is present as $Cr(OH)_3$, and any zinc present is insoluble unless the water is very soft. Small amounts of phenols may be present, since they are occasionally used as a biocide. Most of the solids result from wind-blown dust, since the tower is open to the atmosphere.

Fluid Catalytic Cracker Catalyst Fines

The fluid catalytic cracker catalyst is continuously regenerated by burining off the coke which deposits on the catalyst during the cracking process. The flue gas from the regenerator passes through cyclones that recover the catalyst for reuse. Those particles too small for efficient use in the fluid catalytic cracker are wasted. In addition, electrostatic precipitators downstream of the cyclones are utilized for control of air pollution and collection of very fine particles in the flue gas.

The major component of this waste stream is the catalyst itself, typically a highly refined silica and alumina sand. Trace amounts 0.01 percent or less) of oil are present as residual coke from the regeneration process. Trace metals (particularly vanadium, chromium, and nickel) are deposited on the catalyst during the cracking process. Because of the high temperatures of combustion used in the regeneration process, those metals which do occur are in an oxide or silicate form.

Coke Fines

Coke is produced by refineries for use as an industrial fuel, or is further refined for use as anodes in batteries or in the aluminum industry. The waste stream is generated by product spillage and contamination during loading or storage operations.

The dry waste is almost entirely pure carbon (90 percent); the remaining 10 percent consists of volatile materials, with an ash content of less than 0.1 percent and trace quantities of vanadium and nickel. Both metals originate from the crude supply and are concentrated in the coke, which is the final residual product of the refinery processes. The metals may occur in the carbide form due to the exclusion of oxygen during the coking process.

Conclusions

In this section a detailed discussion of the 17 waste streams in reference to their components has been carried out. Table 2-5 indicates that streams 1 through 10 (Refer to Table 2-5 for their identification) contain oil ranging from 3.5 percent to 64 percent. Once this oil is removed these streams do not contain any potentially hazardous substance in an unstable form. Stream 11, HF alkyation sludge contains potentially hazardous substances in an unstable form and 6.9 percent oil by weight. Since it is impractical to build a sophisticated phase separation system to remove oil from a single stream it is assumed that the proposed phase separation system for streams 1 through 10 will be used on a periodic basis in a batch mode to remove oil from stream 11. This will be followed by a compact lime precipitation of metals.

Streams 12 through 15 (Refer to Table 2-5) contain no oil or any other potentially hazardous substance but are high in water content. Since incineration has been excluded from consideration as a treatment process these streams are processed by calcination. In practice these streams are amenable to dewatering by centrifugation prior to incineration of sludge FCC catalyst fines (stream 16) and coke fines (stream 17) are essentially highly oxidized stable solids with no water or oil in them. These streams do not contain any potentially hazardous unstable compounds and hence need no further treatment.

2.6 Potential Total Market Value of Recoverable Materials and Energy

In order to determine the potential material and energy recovery from the waste streams, the value of recoverable metals and oil is summarized in Table 2-6. Appendix D includes the methodology and detailed tabulations for each of the 17 waste streams. Market value of recovered oil is assumed as $50/metric ton, and the price for metals is taken from October 4, 1976 Chemical Marketing Reporter. The market value of recovered oil is based on an average price of $8 per barrel of crude oil. A quick review of Table 2-6 indicates that total value of metals in all waste streams ($10,889/year) does not justify the recovery. The total value of oil is $360,000 suggesting investigation of methods for possible recovery and reuse of the oil.

2.7 Summary

Sections 2.1 through 2.6 give a brief outline of the purpose and approach to this study. Characterization of the waste streams has identified oil as the only significant potentially hazardous substance requiring recovery or treatment in 11 waste streams. HF Alkylation Sludge is the only waste stream which contains, besides the oil, dissolved metals which require detoxification prior to disposal.

Potential Market Value of Recoverable Materials, identified oil as the only material with recovery potential. Metals accounted for a small dollar value and hence are not worth recovering for reuse. In Section 2.3 we selected a modern refinery as one with 32,000 cu m/day or 200,000 BPSD crude processing capacity, and developed the associated waste generation for the seventeen waste streams.

The following sections develop conceptual systems for recovery of oil, detoxification, incineration and land disposal. Each section includes a discussion of the processes followed by Cost Analysis and Benefits Analysis. Section 8 includes a cost comparison of resource recovery with conventional methods of incineration and land disposal.

TABLE 2-6

MARKET VALUE OF RECOVERABLE MATERIALS AND ENERGY

Stream No.	Waste Stream	Market Value $/Year		
		Oil	Metals	Total
1.	Slop Oil Emulsion Solids	$ 55,200	$ 571	$ 55,771
2.	Silt From Storm Water Runoff	1,100	895	1,995
3.	Exchanger Bundle Cleaning Sludge	975	199	1,174
4.	API Separator Sludge	20,400	508	20,908
5.	Non-Leaded Tank Bottoms	163,200	1,379	164,579
6.	Crude Tank Bottoms	680	8	688
7.	Leaded Tank Bottoms	290	258	548
8.	Dissolved Air Floatation Skimmings	82,500	395	82,895
9.	Kerosine Filter Clays	350	159	509
10.	Lube Oil Filter Clays	28,850	1,134	29,984
11.	Neutralized HF Alkylation Sludge	2,850	217	3,067
12.	Spent Lime From Boiler Feedwater	2,250	658	2,908
13.	Waste Bio Sludge	175	132	307
14.	Once Through Cooling Water Sludge	725	3,032	3,757
15.	Cooling Tower Sludge	-0-	12	12
16.	FCC Catalyst Fines	40	1,323	1,363
17.	Coke Fines	-0-	9	9
TOTALS:		$ 359,585	$ 10,389	$370,474

3.0 SELECTION OF UNIT PROCESSES

3.1 Process Selection

Evaluation of specific characteristics of the 17 waste streams from petroleum refining operations has established the need for recovery of oil from streams 1 through 11, detoxification of treated effluent from HF alkylation sludge and treatment of streams 12 through 15 for removal of small amounts of oil. This section describes the combination of unit processes required for the recovery and reuse of oil from streams 1 through 11 and detoxification of the treated effluent from HF alkylation sludge.

Streams 12 through 15 (see Table 3-1) have high water content and hence the unit processes selected represent dewatering the sludge followed by calcination. For all practical purposes calcination is similar to incineration. FCC catalyst fines (stream 16) and coke fines (stream 17) are highly oxidized stable solids and need no further treatment.

The first column in Table 3-1 lists the waste stream that has to be treated, the second column identifies the appropriate process train and the third column identifies the unit processes. As per the contract agreement between OSW and JEC most of the unit processes were taken from the treatment study (2).

Figure 3-1 is a schematic representation of the selected process train for streams 1 through 11 for phase separation and recovery of oil. Figure 3-2 is specific to HF alkylation sludge and includes the process train in Figure 3-1 and additional unit processes for precipitation of dissolved metals to detoxify the waste stream. Figure 3-3 represents the process train for streams 12 through 15 which includes dewatering and calcination.

If there is a possibility of recovering oil from waste streams 1 through 11 (see Table 3-1), a solvent extraction system is one means of achieving it. This system fundamentally involves four steps, namely, dissolution of oil, phase separation of oil-solvent and solvent-water mixtures recovery of oil and recovery of solvent. In general, solvent extraction processes are efficient in separation of oil and water. Further, solvent losses from a closed loop recovery system are minimal.

Stream 11, HF alkylation sludge, in addition to oil contains dissolved metals which can be precipitated in a lime precipitation system. Basically this involves the addition of lime to increase the pH to 10.5.

TABLE 3-1

SELECTION OF UNIT PROCESSES

Waste Streams	Process Train	Applicable Unit Operations and Processes
(1) Slop Oil Emulsion Solids (2) Silt From Storm Water RunOff (3) Exchange Bundle Cleaning Sludge (4) PAI Separator Sludge (5) Non-Leaded Tank Bottoms (6) Crude Tank Bottoms (7) Leaded Tank Bottoms (8) Dissolved Air Floatation Skimmings (9) Kerosene Filter Clays (10) Lube Oil Filter Clays	See Figure 3-1	Solvent Extraction Centrifugation Decantation Drying Condensation Steam Stripping or Steam Distillation
(11) Neutralized HF Alkylation Sludge	See Figure 3-2	Same as Phase Separation System Plus Precipitation Flocculation Sedimentation Filtration Decantation
(12) Spent Lime (13) Waste Bio Sludge (14) Once Through Cooling Water Sludge (15) Cooling Tower Sludge	See Figure 3-3	Pretreatment (Polymer addition and mixing) Centrifugation Mechanical Separation Calcination Absorbtion
(16) FCC Catalyst Fines (17) Coke Fines	NA	None Required

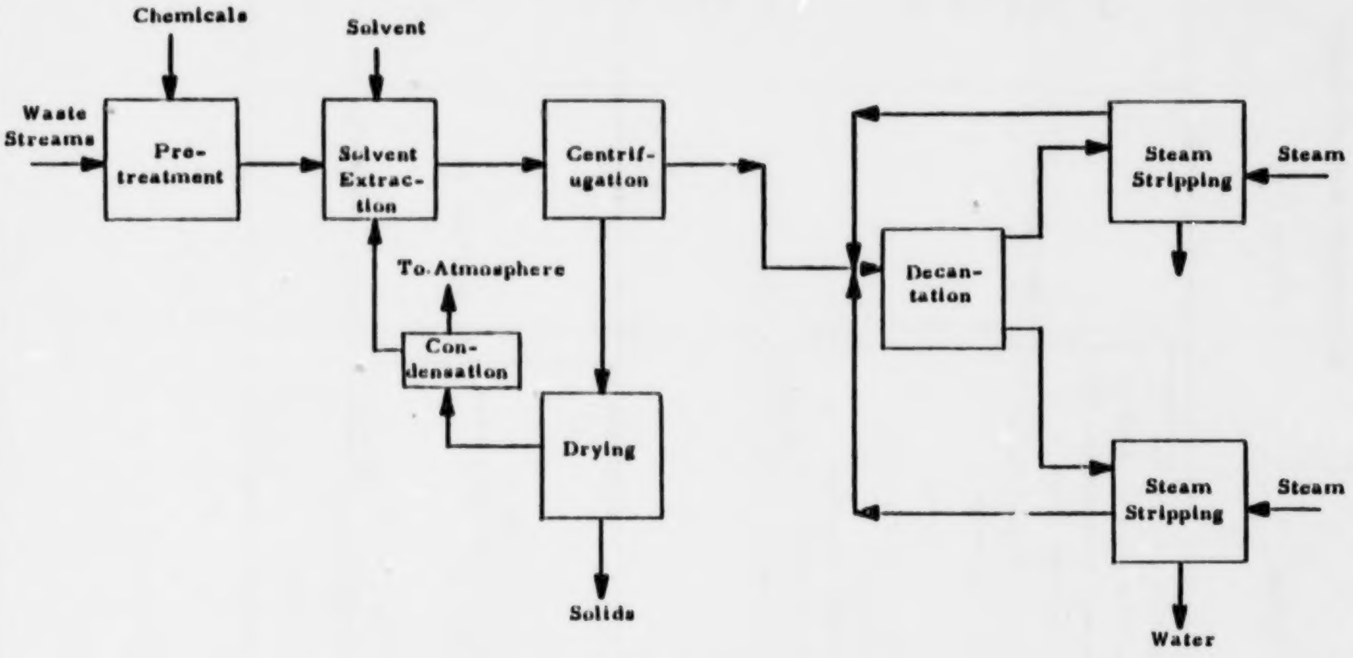

Chemicals
Solvent
Waste Streams
Pre-treatment
Solvent Extraction
Centrifugation
To Atmosphere
Condensation
Drying
Solids
Decantation
Steam Stripping
Steam
Steam Stripping
Steam
Water

FIGURE 3-1

PHASE SEPARATION SYSTEM

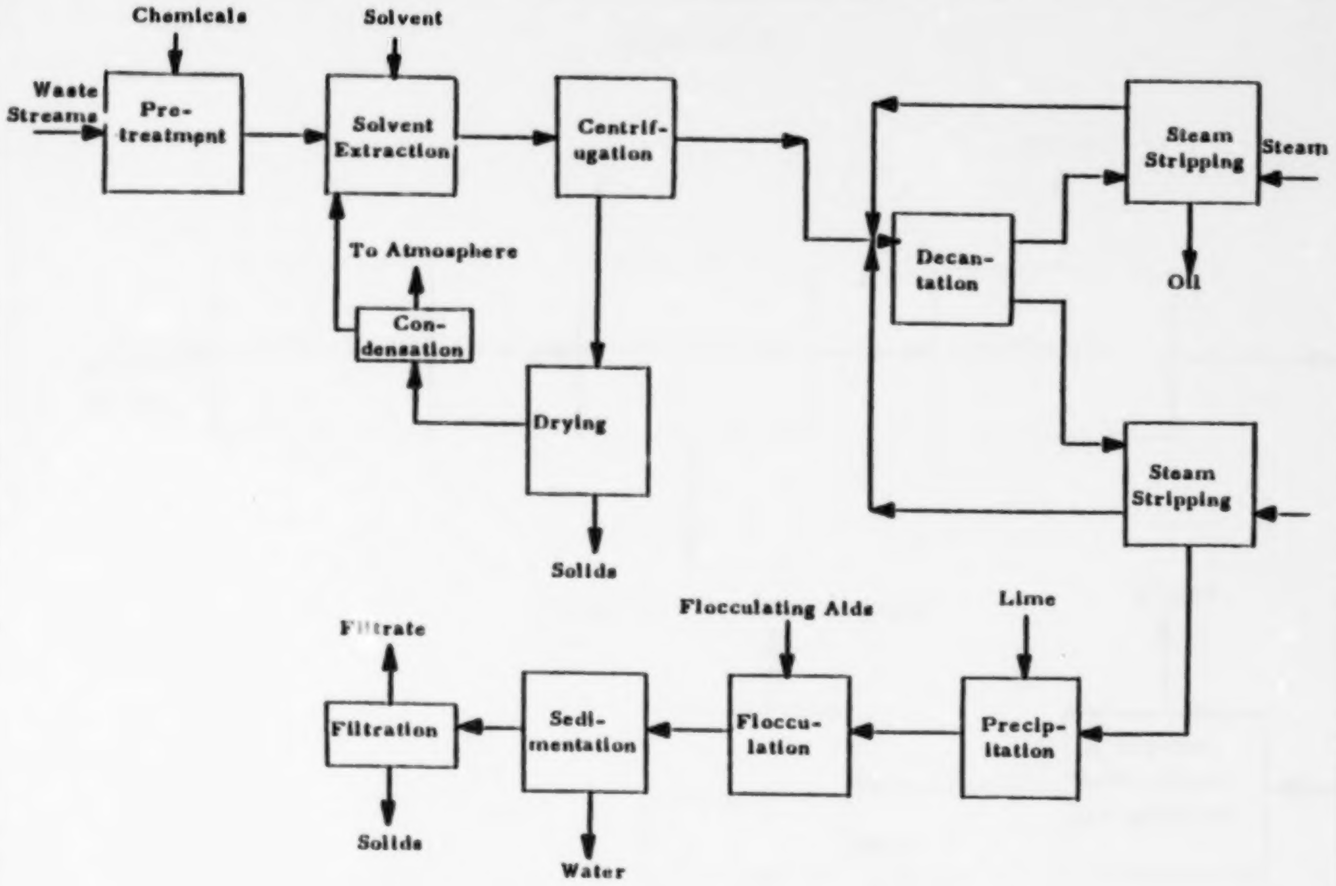

Chemicals
Solvent
Waste Streams
Pre-treatment
Solvent Extraction
Centrif-ugation
Steam Stripping
Steam
Decan-tation
Oil
To Atmosphere
Con-densation
Drying
Steam Stripping
Solids
Flocculating Aids
Lime
Filtrate
Filtration
Sedi-mentation
Floccu-lation
Precip-itation
Solids
Water

FIGURE 3-2

PHASE SEPARATION SYSTEM INCLUDING METALS REMOVAL

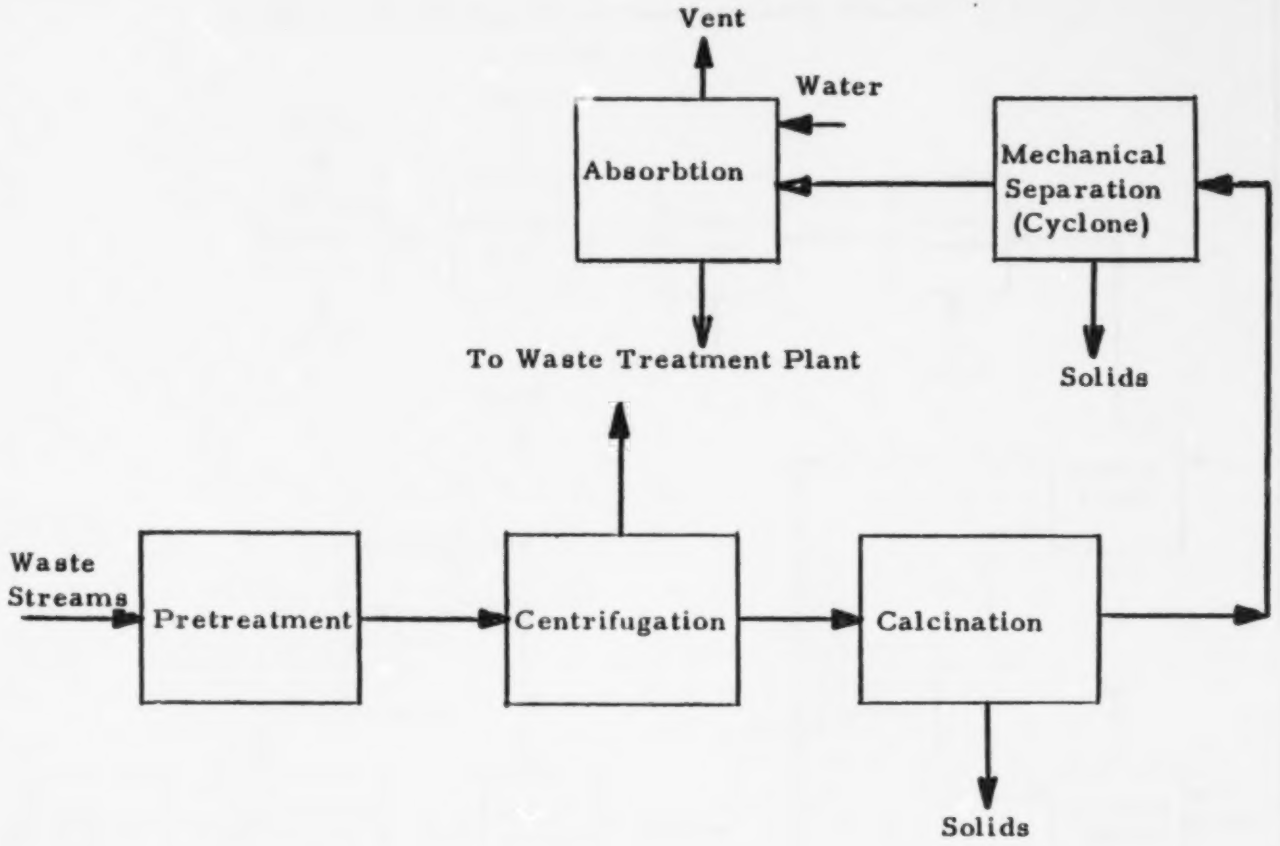

Vent
Water
Absorbtion
Mechanical Separation (Cyclone)
To Waste Treatment Plant
Solids
Waste Streams
Pretreatment
Centrifugation
Calcination
Solids

FIGURE 3-3

CALCINATION SYSTEM

and precipitate the metals as their hydroxides. Most refineries currently practice lime neutralization of HF alkylation sludge prior to discharge, but do not recover the residual oil.

Streams 12 through 15 contain small quantities of oil (less than 0.5%) not sufficient for resource recovery but requiring further treatment for removal. In addition, these streams contain large quantities of water. Hence, the proposed process train consists of centrifugation followed by calcination.

Streams 16 and 17, i.e., FCC catalyst fines and coke fines are highly oxidized stable solids and need no further treatment and have no potential for recovery of metals.

3.2 Unit Processes with Future Potential

This section includes a brief discussion of three unit processes which have a future potential but need further development prior to their application to treatment of waste streams from petroleum refining operations.

Microwave Discharge

Microwave treatment involves the chemical reaction that occurs between microwave generated plasma (partially ionized gas) and the waste streams. The process has been confined to laboratory research studies. Commercial application is rare.

The experiments of oxyten plasma ashing in analytical chemistry does suggest that recovery of trace metal from organic solid waste material is promising. The design parameters of the reactor and plasma chemistry for chemical interaction have to be studied further for the recovery of various metals from waste streams. The process has a potential for commercial applicability at a future date.

Hydrolysis

Hydrolysis applies to reactions in which water brings about a double decomposition with hydrogen going to one component and hydroxyl to the other. Organic hydrolysis takes on a broader aspect and includes reactions in which water is not a reactant. Foster D. Snell Inc. has designed an SO_2 hydrolysis process for sludge containing carbohydrates (with low oil content) to convert the sludge to feed as shown in Figure 3-4. By incorporating an effective oil removal unit operation or process before filtration, the separation of solids from liquids can be

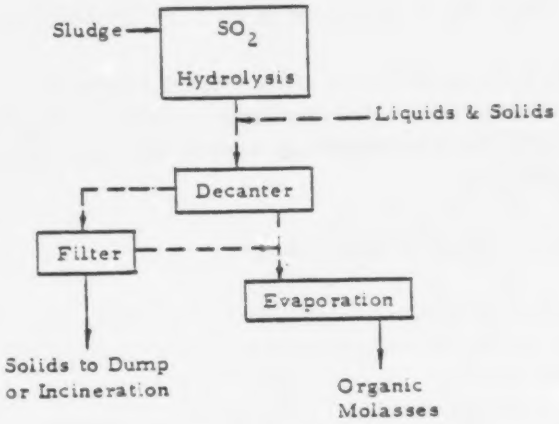

Sludge
SO2
Hydrolysis
Liquids & Solids
Decanter
Filter
Evaporation
Solids to Dump
or Incineration
Organic
Molasses

FIGURE 3-4 HYDROLYSIS

enhanced effectively. The carbohydrate content of the refinery wastes is minimum so the process has to be modified. The cost of evaporation and digestion can be decreased by economical and effective unit designs. Hydrolysis is applicable to waste with a variety of physical forms. This process has a great potential for treatment of hazardous waste streams. The chemical reactions and concepts have to be studied further and additional research is required to develop process and design parameters.

Dissolution

Dissolution reactions involve removal of one or more components from a solid mixture by use of liquid solvent. There are no upper limits to the concentration or amounts of substances that can be removed by dissolution. Sulfuric acid is by far the most widely used. There are relatively few instances of commercial practices in waste treatment. There are a variety of pilot and laboratory studies of waste processing operations which utilize this process as a preliminary step. Other laboratories are working on the recovery of base and exotic metals from industrial waste. Reactions and thermodynamic data have to be developed, but the process has definite potential for recovery of trace metals from solid waste streams.

4.0 PHASE SEPARATION SYSTEM

4.1 Methodology of Solvent Selection

The possibility for recovery of materials and energy from streams 1 through 11 by recovery of oil was defined in Section 2. Section 3 established the applicable unit processes for the Phase Separation System. Prior to detailed design of the system, it is necessary to define the desirable properties and characteristics of applicable solvents and then select the appropriate solvent.

Desirable Properties in Solvents

The selected solvent must readily extract water and oil from the sludge and not form an azeotropic mixture. It is prefereable for the selected solvent to be completely soluble in oil and water at ambient temperatures in order to save energy which will otherwise be needed to maintain a lower or higher temperature. The solvent must have a lower boiling point than water and oil to readily vaporize in the distillation column. In addition the solvent must not react with water and oil to form other products. Since the solvent is recycled many times, it must not age nor react with polymers added to break emulsified oil. The solvent must be available in commercial quantities at reasonable prices and not pose a serious hazard to human health and environment.

Solvent Selection

JEC made a complete review of commercially available solvents with the desirable properties discussed above and determined the following to be the most applicable.

- Acetone
- Ethyl Alcohol
- Ethyl Acetate
- Methyl Alcohol
- Methyl Ethyl Ketone
- Triethyl Amine

The important properties of the above solvents are given in Appendix E. Table 4-1 lists the typical characteristics of acetone. Toxicity and hazardous properties of solvents are very important considerations and are discussed in depth in Section 4.5. Acetone is selected as the solvent of choice for the extraction process for 3 important reasons. First, it is one of the solvents commercially available that has the unique ability to simultaneously dissolve significant quantities of both oil and water. This is critical to the process in keeping both equipment

TABLE 4-1

TYPICAL CHARACTERISTICS OF ACETONE (5)

Boiling point at 760 mm	56.1°C
Coefficient of expansion	0.00080 per °F
Color	Water-white
Critical density	0.238
Critical pressure	47 atm.
Critical temperature	235°C
Dielectric constant at 17°C	20.7
Electrical conductivity at 25°C	6 X 10^8 recip. ohm
Evaporation rate of 95°F	
Minutes 1/4	5%
Minutes 1 1/4	25%
Minutes 2 3/4	50%
Minutes 4 1/4	75%
Minutes 5 1/4	90%
Minutes 5 1/2	95%
Explosive limits	2.15-13.0%
Fire point	18°C (0°F)
Flash point	– 16°C
Freezing point	94.6°C
Heat of combustion	427 Cal./mole (7.373 Cal./g)
Heat of fusion	23.4 cal per g
Latent Heat of Vaporization at 56.1°C	124.5 Cal./g
Melting point	— 95°C
Specific Gravity at 20/20°C	0.790-0.793
Specific Heat at 16°C	0.51 Cal./g
Refractive Index, N 20/D	1.3584
Surface tension at 20°C	23.7 dynes/sq cm
Solubility in water	Complete
Thermal conductivity	0.0004228 (liquid at 0°C)
Viscosity at 25°C	0.316 centipoise
Weight per gallon at 20°C	6.59 lbs.
Distillation range at 760 mm	56.0-57.5°C
Non-volatile matter	1 mg. per 100 ml. (max.)
Purity	99%

and operating costs to a minimum. Second, acetone does not form azeotropes with either oil or water. This permits recovery of high purity acetone for reuse in extraction and allows an oil-water product to be made containing essentially no residual acetone. Minimizing solvent loss, make up requirements and environmental pollution problems. Third, acetone has low toxicity, with a threshold limiting value of 1,000 ppm. The combination of these reasons, plus minimum solvent cost, dictated the use of acetone.

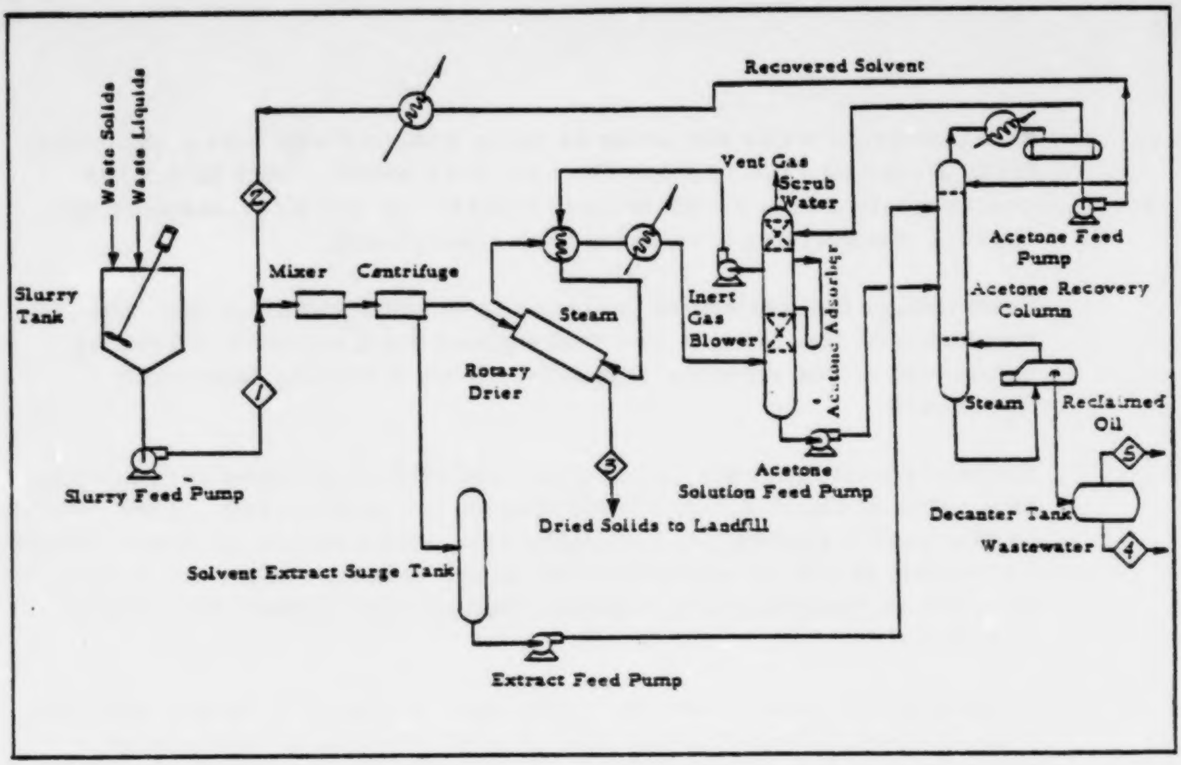
4.2 Details of the Phase Separation System

Figure 4-1 is a schematic of the proposed phase separation system that takes oily solids and liquid refinery waste streams and processes them to produce a dried solids product suitable for landfill, a recovered oil product and reusable wastewater. The proposed treatment scheme is conceptual and has not been tested on refinery wastes. The design capacity of the system is 2100 kgs/hour (6820 lbs/hr).

In Section 3.1 process selection, waste streams 1 through 10 (see Table 3-1) containing significant percentages of oil were grouped together for application of the phase separation system. These ten streams account for a total feed of 26057 metric tons/year, containing 7069 metric tons of oil, 14008 tons of water and 4979 metric tons of solids. Based on the above design capacity streams 1 through 10 can be processed in 350 days. The remaining operating time will be utilized for processing HF alkylation sludge. JEC has assumed that the composition of waste streams will be similar to that analyzed in the industry study (1) and recapped in Table 2-5. It is probable that prior to implementation of a phase separation system, each industry will recover a portion of the oil from those waste streams containing a large percentage of oil. Some of these methods are discussed in Section 9. This factor is not considered in the current study, and may by of significance in developing detailed cost estimates.

Description of the System (see Figure 4-1)

Seven of the ten candidate waste streams are produced periodically in relatively large batches. To keep the treatment plant to minimum size requires processing this material on a continuous basis. This is accomplished by mixing up batches of slurry out of the inventories of solid and liquid wastes and feeding this slurry continuously into the extraction plant. Two slurry mixing feed tanks are provided, each holding eight hours of plant feed capacity. One tank is on the line


Recovered Solvent
Waste Solids
Waste Liquids
Vent Gas
Scrub Water
Slurry Tank
Mixer
Centrifuge
Steam
Inert Gas Blower
Acetone Adsorber
Acetone Feed Pump
Acetone Recovery Column
Rotary Drier
Steam
Reclaimed Oil
Acetone Solution Feed Pump
Slurry Feed Pump
Dried Solids to Landfill
Decanter Tank
Wastewater
Solvent Extract Surge Tank
Extract Feed Pump
1
2
3
4
5

Sample Point		(1)	(2)	(3)	(4)	(5)
Sample Description		Waste Slurry Feed	Acetone Solvent[1]	Dried Solids	Wastewater	Reclaimed Oil
Components -						
Acetone	kgs/hr lbs/hr		7, 647 (16, 823)	0.1 (0.2)		
Oils	kgs/hr lbs/hr	807 (1, 775)		14 (31)		793 (1, 745)
Water	kgs/hr lbs/hr	1, 600 (3, 520		16 (35)	1, 584 (3, 485)	
Solids	kgs/hr lbs/hr	568 (1, 250)		568 (1, 250)		
TOTAL:	kgs/hr lbs/hr	2, 975 (6, 545)	7, 647 (16, 823)	598.1 (1, 316)	1, 584 (3, 485)	793 (1, 745)

(1) - Rate Varies with Slurry Composition.

FIGURE 4-1

PHASE SEPARATION SYSTEM
PROCESS FLOW DIAGRAM

being emptied while the other is being charged with waste products from a holding tank to form the next feed batch. Both tanks are continuously stirred with mixers to keep the solids in suspension thereby maintaining a uniform feed consistency.

Even though the system is designed to operate continuously, the provision of two 8-hour feed tanks gives the flexibility of feeding individual waste streams separately from a holding tank when necessary.

Slurry is pumped from the on-line feed tank and mixed with acetone in a ratio of about 2.5 parts acetone to 1.0 part slurry. This mixture is thoroughly agitated in a Kennics type static mixer to obtain maximum extraction of the oil and water out of the slurry. After extraction, the mixture is centrifuged to separate out the solids from the extract solution.

A high-speed continuous type centrifuge is used for solids removal. This unit permits the production of a solids product containing a minimum amount of residual solution, and it produces these solids at a steady continuous rate for feeding into the drier. The extract solution from the centrifuge is stored in a surge tank for further processing.

The damp solids from the centrifuge fall into a hopper and are then fed via a screw conveyor into the drier, a steam heated rotary kiln, heats the solids to a temperature of 300°F. This insures the production of a dried product containing a minimum of 95 weight percent solids. After drying the solidsa are taken via a screw converyor to a hopper for subsequent disposal in a sanitary landfill.

The solvent and water vapors evolved during the drying are continuously purged from the drier by a circulating stream of nitrogen. These vapors are cooled and then fed into an absorber for removal of the acetone. The absorber is a packed tower containing the equivalent of about six trays. Water entering at the top scrubs the vapors removing the bulk of the acetone vapor. The stripped nitrogen gas is recirculated back to the drier via a gas blower and the water-acetone bottoms product solution is pumped to the distillation column for acetone recovery.

Both the centrifuge extract solution and the absorber bottoms product are pumped to the distillation column as feeds. The distillation column, containing 26 trays, fractionates these feeds into a 99 weight percent acetone overhead product and an oil-water bottoms product containing less than 10 ppm acetone. The overhead acetone product is cooled and recycled back to the extraction operation. The oil-water bottoms product flows to a decanter tank for phase separation. Recovered oil from the decanter tank is sent back to the refinery for reprocessing, and the water is sent to the refinery sewer system.

The feeds to the distillation column contain small amounts of dissolved inert gases. These gases are stripped out in the distillation column and appear as an overhead vent gas product. This vent gas is scrubbed with water in a packed column (vent gas scrubber) to remove trace amounts of acetone before being vented to the atmosphere. The liquid from the vent gas scrubber is utilized as the water feed to the top of the absorber.

The design of both the absorber and the distillation column was verified by computer studies. Experimental data from the literature was utilized to develop both equilibrium and enthaply data as inputs to the computer program. Using these inputs, the computer program calculates the column performance for a specified number of trays. Output data from the program includes reboiler duty, condenser duty, product recovery and purity, and a complete tray by tray description of the vapor and liquid flow rates, compositions, and temperatures. The reboiler and condenser duties are used directly to specify these pieces of equipment. The tray vapor-liquid flow data is used to size the columns.

Table 4-2 shows the mass balance for the phase separation system. By its nature this system is best operated on a continuous basis and hence the assumption of 8760 operating hours is reasonable. Specifications for each of the units in the system are included in Appendix E.

4.3 Cost Analysis

This section includes a detailed cost analysis of the phase separation sys to treat combined waste streams 1 through 10 for a 32,000 cu m/day or 200,000 BPSD refinery. The total estimated capital cost is $1,512,000.

Capital Costs

Table 4-3 gives a complete equipment list and itemized costs. Equipment costs are vendor quotations after review of the

Sample Point		(1)	(2)	(3)	(4)	(5)
Sample Description		Waste Slurry Feed	Acetone Solvent(1)	Dried Solids	Wastewater	Reclaimed Oil
Components -						
Acetone	kgs/hr lbs/hr		7,647 (16,823)	0.1 (0.2)		
Oils	kgs/hr lbs/hr	807 (1,775)		14 (31)		793 (1,745)
Water	kgs/hr lbs/hr	1,600 (3,520		16 (35)	1,584 (3,485)	
Solids	kgs/hr lbs/hr	568 (1,250)		568 (1,250)		
TOTAL:	kgs/hr lbs/hr	2,975 (6,545)	7,647 (16,823)	598.1 (1,316)	1,584 (3,485)	793 (1,745)

(1) - Rate Varies with Slurry Composition.

TABLE 4-2

MASS BALANCE OF PHASE SEPARATION SYSTEM

TABLE 4-3

ESTIMATE OF INSTALLED EQUIPMENT COST

Item No.	Description	Quantity	Equipment or Unit Cost	Multi-plying Factor	Installed Cost
K-1	Circulating Gas Blower	1	$ 200	4	$ 800
E-1	Dryer Effluent - Nitrogen Exchanger	1	150	4	600
E-2	Absorber Feed Cooler	1	175	4	700
E-3	Acetone Feed Cooler	1	1,700	4	6,800
E-4	Distillation Condensor	1	15,000	4	60,000
E-5	Distillation Reboiler	1	9,000	4	36,000
V-1 & 2	Slurry Tank	2	8,000	3	24,000
V-3	Acetone Accumulator	1	4,000	4	16,000
V-4	Decanter Tank	1	3,000	3	9,000
P-1	Acetone Feed Pump	2	3,400	3	10,200
P-2	Feed Slurry Pump	2	3,600	3	10,800
P-3	Centrifuged Extract Pump	2	3,200	3	9,600

TABLE 4-3

ESTIMATE OF INSTALLED EQUIPMENT COST (Cont'd.)

Item No.	Description	Quantity	Equipment or Unit Cost	Multi-plying Factor	Installed Cost
P-4	Aqueous Acetone Pump		$ 1,900	3	$ 5,700
A-1	Kenics Static Mixer Element	2	400	4	1,600
A-2 & 3	Slurry Agitator	1	2,000	4	8,000
D-1	Porcupine Solids Dryer	1	44,000	4	176,000
F-1	Centrifuge	1	75,000	4	300,000
X-1 & 2	Screw Conveyors	2	16,000	4	64,000
V-5	Extract Surge Tank	1	2,500	3	7,500
C-1	Acetone Absorber	1	8,750	5	43,750
C-2	Acetone Distillation Column	1	40,000	5	200,000
	TOTALS:		$241,975		$991,050
					Say $1,000,000

specifications in Appendix E. The installed cost for each equipment is determined by a multiplying factor between 3 to 5 which varies with the nature of the equipment, time and effort required for installation and nature of the job. This method of estimation is accurate to within ±30 percent. To determine the total capital cost, the costs for the land, design, engineering, construction management, fee for profit and contingency are added to the installed cost. From Table 4-4 the estimated capital cost for this system is $1,512,000 in December 1976 dollars.

Annual Operation and Maintenance Costs

Table 4-5 gives a breakdown of the various elements making up the operation and maintenance costs. EPA has specifically instructed that energy costs be excluded from operation and maintenance costs and be shown as a separate item.

The phase separation system, combined with the calcination system, will need a total of 5 operators. For purposes of this cost analysis the total operator costs are split 60 percent and 40 percent between the two systems. All the other items in Table 4-5 are based on the cost element data furnished to JEC by EPA (4). The annual operating cost for the system is $232,000.

Energy Costs

The proposed phase separation system needs 4,536 kgs/hr is low pressure steam. Most refineries of the size contemplated have low pressure waste steam that can be utilized for this purpose. Table 4-6 is an itemized list of all energy costs giving a total of $153,000 per year.

Value of Benefits Derived

The phase separation system recovers 95 percent of the oil in the waste sludge, accounting for a dollar recovery of $347,500. Further, the recovered oil results in a decreased cost for waste disposal. The total dollar value of benefits is $451,500 (Table 4-7).

Conclusions on Cost Analysis

Table 4-8 is a summary of the cost analysis for the phase separation system for a 32,000 cu m/day (200,000 BPSD) refinery. The capital cost is $1,512,000, the operation and maintenance costs are $232,000,

TABLE 4-4

CAPITAL COST ESTIMATE

(± 30 Percent)

Installed Equipment Cost (Table 4-8)	$ 1,000,000
Land - 0.81 Hectares @ $12,400/Hectares	10,000
Design and Engineering	150,000
Construction Management and Fee	100,000
	$ 1,260,000
Contingency 20%	252,000
Total Capital Cost	$ 1,512,000

TABLE 4-5

ESTIMATED ANNUAL OPERATION AND MAINTENANCE COST

OPERATING HOURS - 8760

Direct Labor (1) 3 Operators @ $9/Hr.	$	56,160
Supervision and Administrative (2)		28,080
Make up Water		6,300
Acetone Make up		550
Maintenance 4% of Capital		60,000
Taxes and Insurance 4% of Capital		60,000
Cost of Land Disposal		210,000
TOTAL	$	232,090

(1) Phase separation system and the calcination system together need 5 operators as follows: day shift (two) evening shift (one) night shift (one) replacements (one)

(2) 50% of direct labor

TABLE 4-6

ENERGY COSTS AND USAGE (ANNUAL)

OPERATING HOURS 8760

Electric Power 100 kw/hr at $.03/kw/hr	$ 26,280
Steam low Pressure (1) 1.05 kg/cm^2, 3856 kg/hr	74,460
Steam high Pressure 10.5 Hkg/cm^2, 682 kg/hr at $8.8/1000 kgs	52,560
	$ 153,300

TABLE 4-7

VALUE OF BENEFITS DERIVED

(ANNUAL)

Recovery of Oil 6950 MT/Year (2)	$ 347,500
Reduced Disposal Costs[3]	104,000
	$ 451,500

---

(1) JEC has given a credit of $1/454 kgs of steam. It must be noted noted that low pressure steam is normally available in ample quantities as waste steam in large petroleum refineries. For example a 200,000 BPSD refinery will have a generating capacity of 130,000 - 200,000 kgs/hr.

(2) Value of Recovered oil $50/MT ($8/barrel) This is 70 percent of the price of crude oil in the world market.

(3) Credit of $5/MT for reduced landfarming costs.

TABLE 4-8

COST ANALYSIS SUMMARY

PHASE SEPARATION SYSTEM

32,000 cu m/day (200,000 BPSD)

Capital Cost (Table 4-4)	$1,512,000	
Operation and Maintenance Costs	(Table 4-5)	232,090
Energy Costs and Usage	(Table 4-6)	153,300
Value of Benefits Derived	(Table 4-7)	(451,500)
Net Operating Costs		$ (66,110)*
Amortization of Capital Cost at 10%, 10 Yrs.		
Capital Recovery Factor 0.1627		$ 246,000
Net Annual Costs		$ 179,890
Total Treatment Cost Wet Basis		$ 6.90/MT
Total Treatment Cost Dry Basis		$36.13/MT
Product Cost Impact		15 mills/Cu M

*There is a net revenue from the value of benefits derived.

energy costs $153,000 and value of benefits derived is $451,500. The net annual costs after amortizing the capital at 10% over 10 years is $179,890; say $180,000. The product cost impact of the phase separation system is 15 mills/cu m.

4.4 Benefits' Analysis

The primary benefit of implementing the phase separation system to treat waste streams 1 through 10 is recovery and reuse of oil. Oil, by definition, is a potentially hazardous substance and hence its recovery will detoxify one element of the wast streams. The other potentially hazardous substances occur in a stable form. The phase separation system contributes to the recovery of products and energy in addition to achieving a disposal cost reduction. Table 4-9 is a summary of the benefits derived.

4.5 Environmental and Safety Aspects

The vent gas is moist air with trace amounts of acetone (less than 10 ppm) and hence does not contribute to air pollution. The wastewater is essentially heated water which has no pollution load and may be reused as washwater.

Hence, the proposed phase separation system will not contribute to any air or water pollution problems, but by their very nature solvents possess certain toxic and hazardous properties requiring special handling.

Toxicity and Hazardous Properties of Selected Solvents

Many of the most useful properties of solvents are a result of volatility. The rate of vaporization depends on many factors: the chemical nature of the solvent, the temperature, the pressure and the rate of air flow or passage over its surface. As a result of vaporization, especially in confined areas or in still air, a high concentration of the molecules of the solvent develops in the air immediately above it. It is this vapor/air mixture which is actually flammable rather than the liquid itself. Thus volatility, useful as it is, carries with it the penalty of fire hazard. Fans and other ventilating devices are among the most essential means of reducing flammability hazards in a plant where solvent vapors are likely to accumulate, as they prevent development of high concentrations of fumes.

TABLE 4-9

BENEFITS' ANALYSIS

PHASE SEPARATION SYSTEM

	Treatment		REMARKS
	Before	After	
Detoxification	7069 MT	350 MT	95% Destruction
Volume Reduction	26057 Cu. M	5238 Cu. M	80% Volume Reduction
Product Recovery	None	6950 MT	Oil for Reuse
Energy Recovery	None	6950 MT	Oil as Energy
Disposal Cost Reduction	$130, 000	$26, 000	Gain of $104, 000

* Oil in Sludge

The three properties having to do with flammability are flash point, fire point and auto ignition point, and they are defined as: a) Flash Point, the lowest temperature at which a liquid will give off enough vapor to continue to burn when once ignited; b) Auto Ignition Point, the temperature at which a mixture of a solvent vapor and air will ignite without the aid of a spark or flame is known as the auto ignition point of the solvent.

Another property closely related to the flammability is the explosive range and is defined as the range of vapor in air which will propagate a flame, or which will explode under confined conditions.

The last and the most important safety property is the toxicity and it refers to substances that are poisonous or harmful in very low concentrations, and is described by its effects on living organisms.

Table 4-10, 4-11, and 4-12 give the flammability, hazardous, and TLV values for selected solvents that are capable of treating the wastes from the petroleum refineries.

Safety Precautions

The following precautions have to be undertaken for safe storage, handling and control of toxicity.

Storage

Storage of the solvent poses a potential hazard and the following precautions have to be taken for safety:

(a) Location of the tank at a sufficiently low level so that liquids will drain to, instead of away from, the storage tank.

(b) No bottom openings whatsoever. The storage tanks should be discharged by pumping through pipes inserted at the top and extending nearly to the bottom.

(c) Each tank should be equipped with a relief vent fitted with a flash arrestor.

(d) All tanks and pipelines should be grounded to reduce the danger of ignition by static electricity.

TABLE 4-10 FLAMMABILITY PROPERTIES OF SELECTED SOLVENTS (6)

NAME OF SOLVENT	SYNONYMS	FLASH POINT, °F		EXPLOSIVE LIMIT % by VOLUME IN AIR		AUTO IGNITION TEMPERATURE, °F	SUSCEPTIBILITY TO SPONTANEOUS HEATING
		CLOSED CUP	OPEN CUP	LOWER	UPPER		
Acetone	Dimethyl Ketone		15	2.15	13.0	1118	No
Ethyl Acetate	Acetic Ether	24	30	2.18	11.5	907	No
Ethyl Alcohol	Ethanol	55	----	3.28	19	799	No
Methyl Alcohol	Methanol	54	60	6.0	36.5	878	No
Methyl Ethyl Ketone	2-Butanone	30	----	1.81	11.5	----	No
Triethyl Amine		----	20	1.2	8		

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TABLE 4-11 HAZARD ANALYSIS OF SELECTED SOLVENTS (6)

SOLVENT	ACUTE LOCAL			ACUTE SYSTEMIC			CHRONIC LOCAL		CHRONIC SYSTEMIC			TOXICOLOGY
	Irritant	Ingestion	Inhalation	Ingestion	Inhalation	Skin Absorption	Irritant	Inhalation	Ingestion	Inhalation	Skin Absorption	
Acetone	1	2	2	2	2	2	1		1	1	1	Acetone is narcotic in high concentrations. Headache may result from prolonged inhalation.
Ethyl Acetate	1			2	2	2	1		1	1	1	Ethyl acetate is irritating to mucous surfaces, particularly the eyes, gums and respiratory passage, and is also mildly narcotic. On repeated or prolonged exposures, it causes conjunctival irritation and corneal clouding.
Ethyl Alcohol	1			2	2	1	1		1	1	1	Exposure to concentrations of 5,000 to 10,000 ppm results in irritation of the eyes and mucous membranes of the upper respiratory tract. Exposure to concentrations of over 1,000 ppm may cause headache, irritation of the eyes, nose and throat, and if long continued, drowsiness, lassitude, appetite loss and inability to concentrate.
Methyl Alcohol	1		1	3	2	2	1	1	2	2	2	Methyl alcohol possesses distinct narcotic properties. It is also a slight irritant to the mucous membranes. Though single exposure to fume may cause no harmful effect, daily exposure may result in the accumulation of sufficient methyl alcohol in the body to cause illness. Severe exposure may cause dizziness, unconsciousness, sighing, respiration, cardial depression & eventually death.
Methyl Ethyl Ketone	1	1	1		2		1			U		Produces local irritation and narcosis. Does not have high degree of chronic toxicity.
Triethyl Amine	3			3	3		2	2		3	3	Experimental animals have shown kidney and liver damage.

NOTE: See following page for explanation of Toxic Hazard Rating Code.

(Attachment to Table 4-11)

Toxic Hazard Rating Code

0 = None: (a) No harm under any conditions

(b) Harmful only under unusual conditions or overwhelming dosage

1. Slight: Causes readily reversible changes which disappear after end of exposure

2. Moderate: May involve both irreversible and reversible changes not severe enough to cause death or permanent injury.

3. High: May cause death or permanent injury after exposure

U. Unknown: No information on humans considered valid

TABLE 4-12

THRESHOLD LIMITING VALUES (TLV) (6)

Solvent	ppm	mg/m^3
Acetone	1,000	2,400
Ethyl Acetate	400	1,400
Ethyl Alcohol	1,000	1,900
Methyl Alcohol	200	260
Methyl Ethyl Ketone	250	590
Triethyl Amine	25	100

mg. of substance per cubic meter of air

Safe Handling

A well-planned safety program for the safe handling of solvent consists of: a) Identification of hazardous operations; b) Analysis of the hazards; c) Engineering controls; d) Personal protection of employees; e) Medical protection; f) Supervision; g) Employee education; h) All flames and smoking must be eliminated; i) All sources of sparks must be removed, rubber soled shoes and nonferrous tools should be employed; j) Main supplies of solvents should be stored in a fireproof storage building; k) In spray booths, all parts of the system should be constructed of fire resistant material, and all surfaces should be smooth to facilitate routine cleaning.

Prevention of Exposure (toxicity)

The general underlined methods will reduce the concentration of the solvent and hence the toxicity inside and outside the treatment plant.

Control at Point of Origin of Contaminant

Control at point of origin of contaminant such as use of, a) Local exhaust ventilation, b) Wet methods for particulate matter, c) Dilution of contaminated with uncontaminated air by general ventilation, d) Good maintenance and good housekeeping, e) Use of personal respiratory protective devices, such as gas masks and respirators.

4.6 HF Alkylation Sludge

In Section 2, the characteristics of HF Alkylation Sludge were outlined with the note that metals in this stream are more readily soluble and hence potentially hazardous. Table 2-5 indicates the compositions of the stream to be 57 MT of oil, 320 MT of solids and 446 MT of water, for a total of 823 MT per year. To provide a system for recovering the oil and detoxification of the soluble metals in the waste stream, it is proposed that the waste stream be taken through the phase separation system discussed earlier, and further that the effluent be treated with lime at high pH to precipitate all metals as their hydroxides. Section 3 outlined the various unit processes required for this purpose.

Based on the system design capacity of 3100 Kg/hour, it will take 11 days to process the HF alkylation sludge through the phase separation system. The actual mechanics of whether all of the HF alkylation sludge will be processed at one time or on a periodic basis depends on the individual requirements of each operation.

In this section we develop the various elements of the lime precipitation system. For purposes of estimating the costs incurred for phase separation, it is assumed that the already proposed solvent extraction system will be utilized, proportioning the capital, operation and maintenance and other costs gased on the quantity treated.

Lime Precipitation System (Figure 4-2)

The effluent from the phase separation system is essentially reclaimed water with dissolved metals. The total quantity is 446 MT to be treated in 11 days since the waste stream is processed during that period in the phase separation system. Hence, the design flow for the lime precipitation system is 27 liters per minute (lpm).

The effluent water from the phase separation system is blended with lime in a holding tank until a pH of 10.5 is reached and then allowed to settle for 10 hours.

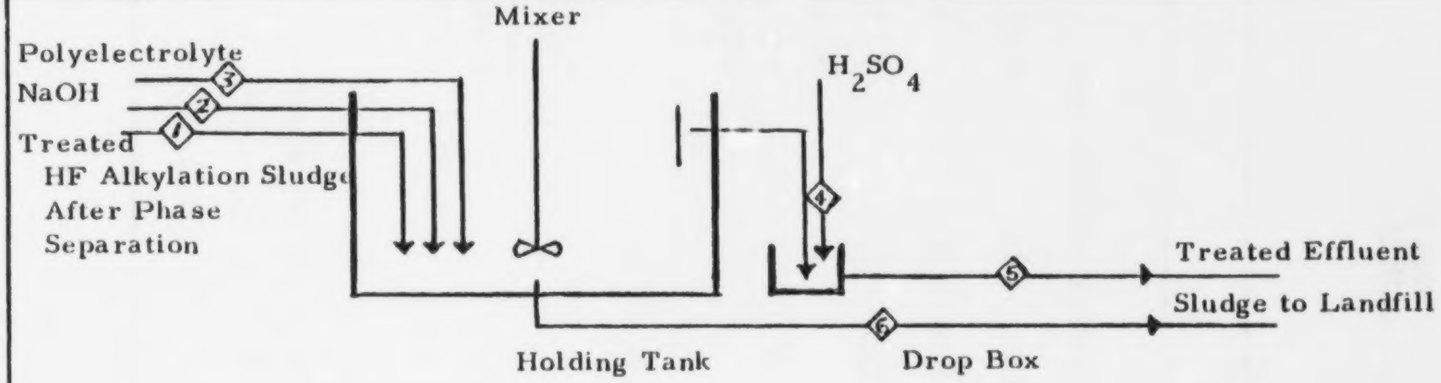
The system is operated in batches by having two holding tanks with a capacity of 19,000 liters each. The holding tank is provided with a 4 HP mixer to blend the sodium hydroxide with the waste effluent. Clear liquor with a pH of 10.5 is pumped into a drop box where sulfuric acid is added to reduce the pH to between 8 and 9 for final discharge. The settled sludge (3,800 lpd) is taken to a secured landfill. Polelectrolyte will be added to the holding tank liquor to produce a better quality effluent. The system described above is a small one requiring small tanks, and low capacity pumps which will be supplied as a package system by equipment manufacturers.

Cost Analysis

Table 4-13 is a summary of the cost analysis for the lime precipitation system for HF alkylation sludge. The total annual costs for the system if $39,674. Table 4-14 through 4-17 give details on capital, operation and maintenance, energy costs, and value of benefits derived. The product cost impact of lime precipitation system is 3 mills/cu m.

Benefits' Analysis

The benefits' analysis discussed in Sections 4.4 and 4.5 for phase separation system are applicable in their entirety to this section as


Mixer
Polyelectrolyte
NaOH
Treated
HF Alkylation Sludge
After Phase
Separation
3
2
1
H_2SO_4
4
5
6
Treated Effluent
Sludge to Landfill
Holding Tank
Drop Box

Sample Point	(1)	(2)	(3)	(4)	(5)	(6)
Sample Description						
Metals kg/hr	0.4	---	---	---	.02	.38
Water kg/hr	1688.6	6	.005	1	1688.00	7.6
Solids kg/hr	---	---	---	---	02	.02
Total	1689.0	6	.005	1	1688.04	8.0

FIGURE 4-2

LIME PRECIPITATION SYSTEM
(Batch Operation)

TABLE 4-13

COST ANALYSIS SUMMARY
HF ALKYLATION SLUDGE

ITEM		
Capital Cost	(Table 4-14) $110,000	
Operation and Maintenance Cost	(Table 4-15)	$ 22,180
Energy Costs and Usage	(Table 4-16)	4,844
Value of Benefits Derived	(Table 4-17)	(5,350)
Net Operating Costs:		$ 21,674
Amortization of Capital Cost at 10%, 10 yrs		
Capital Recovery Factor 0.1627		18,000
Net Annual Costs:		$ 39,674
Total Treatment Cost Wet Basis	$ 48.20/MT	
Total Treatment Cost Dry Basis	$123.98/MT	
Product Cost Impact	3 mills/cu.m	

TABLE 4-14

CAPITAL COST ESTIMATE

ITEM	
Package Lime Precipitation System	$ 60,000
Land	Negligible
Phase Separation System (proportional cost)	50,000
System(1) Total:	$110,000

TABLE 4-15

ESTIMATED ANNUAL OPERATION AND MAINTENANCE COSTS

ITEM		
Phase Separation System	(proportional cost)	$ 6,700
Lime Precipitation System		
Sodium Hydroxide		200
Maintenance	4% of Capital	2,400
Taxes and Insurance	4% of Capital	2,400
Operator Cost	2 hrs/day	6,570
Supervision and Administrative		3,285
Disposal of Sludge to Chemical Landfill		625
	TOTAL	$ 22,180

TABLE 4-16

ENERGY COSTS AND USAGE
(ANNUAL)

ITEM	
Proportional Cost for Phase Separation System	$ 4,844
Energy Costs for Lime Precipitation System	Negligible
Total:	$ 4,844

TABLE 4-17

VALUE OF BENEFITS DERIVED

ITEM	
Recovery of Oil 57 MT	$ 2,850
Reduced Disposal Costs	2,500
Total:	$ 5,350

well. In addition, the lime precipitation system does not create any air or water pollution problems.

5.0 CALCINATION SYSTEM

5.1 Details of Calcination Process

The possibility for calcination of waste streams 12 through 15 (see Table 5-1) containing residual amounts of oil was established in Section 2 and Section 3 listed the various unit processes required for the calcination system. This section describes the calcination system and develops a complete mass balance. Appendix G includes detailed calculations supporting the design and mass balance calculations.

Calcination is the process of conversion by thermal decomposition at elevated temperatures of aqueous liquids and sludges into solid materials without any interactions with gaseous phases. The calcination process concentrates the wastes, destroys organic components and leaves inorganic compounds in a more stable, nonleachable form for disposal in a sanitary landfill. Calcination essentially converts the components of the waste stream into their stable state by driving off volatile materials. Table 5-2 provides a complete mass balance for a typical process. Figure 5-1 is a schematic of the calcination system.

Process Description

Two of the four candidate waste streams are produced periodically in relatively large batches. To keep the treatment plant to a reasonable size requires processing all material on a continuous basis. This is accomplished by mixing up batches of slurry out of inventories of solid and liquid wastes and feeding this slurry continuously into the calcination plant. Both the holding tank and slurry feed tanks are continuously stirred with mixers to keep the solids in suspension thereby maintaining a uniform feed consistency.

A polymer is added to the slurry feed pump to increase the efficiency of liquid/ solid preparation in the centrifuge. A high speed continuous type centrifuge is used which permits the production of a feed containing minimum amount of residual solution, and it produces these solids at a steady continuous rate for feeding into the rotary kiln calciner. The extract solution or centrate is discharged to the wastewater treatment plant. A portion of the centrate is used as a scrubbing medium to absorb the fine particulates in the flue gas from the calciner.

The damp solids from the centrifuge fall into a hopper and are then fed via a screw conveyor into the rotary kiln calciner. The calciner is

TABLE 5-1

CALCINATION SYSTEM

OPERATING HOURS 8760

Stream Number	Waste Stream	Total Quantity MT/Yr	Oil, MT/Yr	Water, MT/Yr	Solids MT/Yr
12	Spent Lime From Boiler Feed Water Treatment	14,200	45	8,378	5,777
13	Waste Bio Sludge	1,258	4	1,094	160
14	Once Through Cooling Water Sludge	3,380	15	845	2,520
15	Cooling Tower Sludge	24	0	18	6
	TOTALS:	18,862	64	10,335	8,463

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TABLE 5-2

MASS BALANCE FOR CALCINATION SYSTEM

OPERATING HOURS 8760

Sampling Point	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sample Description	Waste Slurry Feed	Centrifuge Feed	Wet Cake From Centri-fuge	Dry Solids From Calciner	Centrate From Centrifuge	Flue Gas From Calci-ner	Flue Gas From Cyclone	Flue Gas To Stack
Flow, kg/hr *	2,153	2,153	1,148	907	1,005	2600	26.32	26.2
(lbs/hr)	(4,737)	(4,741)	(2,529)	(1,996)	(2,212)	ACMM	ACMM	ACMM
Components:								
Solids, kg/hr	966	966	918	907	48	11		
(lbs/hr)	(2,125)	(2,125)	(2,020)	(1,996)	(105)	(24)		
Water, kg/hr	1,180	1,180	224	—	956			
(lbs/hr)	(2,596)	(2,596)	(4,961	—	(210			
Oil, kg/hr	7	7	6	—	1			
(lbs/hr)	(16	(16)	(13)	—	(3)			
Polymer, kg/hr	---	**	0	—	**			
(lbs/hr)	---	(4)	(0)	—	(4)			

* 1 kg = 2.2 lbs ACMM - Actual Cubic Meters Per Minute ***ACCM - Actual cubic meters per minute.

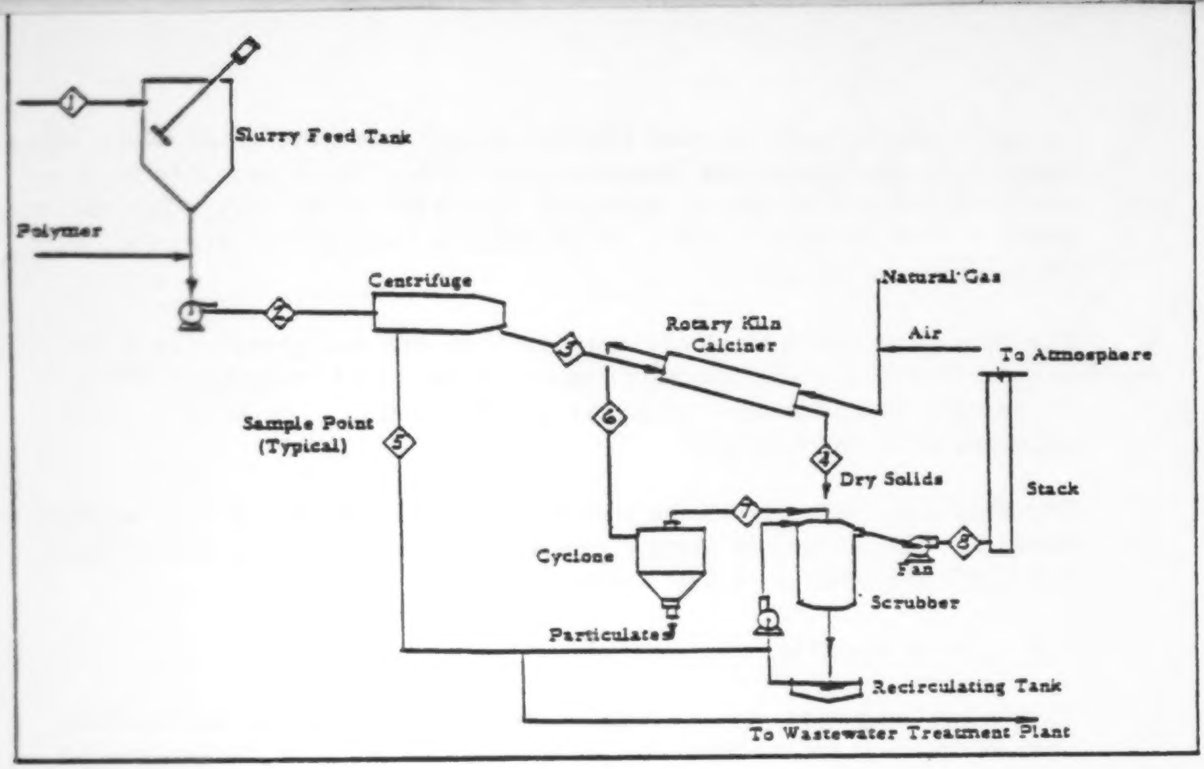

1
Slurry Feed Tank
Polymer
2
Centrifuge
Natural Gas
Rotary Kiln
Calciner
Air
To Atmosphere
3
Sample Point
(Typical)
5
6
4
Dry Solids
Stack
7
8
Cyclone
Fan
Scrubber
Particulates
Recirculating Tank
To Wastewater Treatment Plant

FIGURE 5-1

CALCINATION SYSTEM

Sampling Point	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sample Description	Waste Slurry Feed	Centrifuge Feed	Wet Cake From Centri-fuge	Dry Solids From Calciner	Centrate From Centrifuge	Flue Gas From Calciner	Flue Gas From Cyclone	Flue Gas To Stack
Flow, kg/hr*	2,153	2,153	1,148	907	1,005	2,600	26.32	26.2
(lbs/hr)	(4,737)	(4,741)	(2,529)	(1,996)	(2,212)	ACMM***	ACMM	ACMM
Components:								
Solids, kg/hr	966	966	918	907	48	11		
(lbs/hr)	(2,125)	(2,125)	(2,020)	(1,996)	(105)	(24)		
Water, kg/hr	1,180	1,180	224	---	956			
lbs/hr)	(2,596)	(2,596)	(4,961	---	210			
Oil, kg/hr	7	7	6	---	1			
(lbs/hr)	(16)	(16)	(13)	----	(3)			
Polymer, kg/hr	---	**	0	----	**			
(lbs/hr)	---	(4)	(0)	----	(4)			

*1 kg = 2.2 lbs

**10 mg/liter

***ACCM - Actual Cubic Meters Per Minute inclined slightly and the feed travels slowly down the sides while being exposed to the increasing temperature. The kiln is provided with air seals for controlled and economical operation of the unit. The thermal efficiency of the kiln is about 65 percent and the kiln is operated with 20 percent excess air.

The flue gas leaving the calciner contains various gases, (such as carbon dioxide, sulfur dioxide) water vapor and some particulates. To remove particulates and gases the flue gas is treated in a cyclone followed by a wet scrubber.

The calcined solids from the rotary kiln are disposed of in a sanitary landfill. The scrubber sludge contains 2 percent solids and amounts to 96 MT per year on a dry basis.

5.2 Cost Analysis

The following pages give a detailed cost analysis of the calcination system to treat waste Streams 12 through 15 for a 32,000 cu m/day or 200,000 BPSD refinery.

Capital Costs

Table 5-3 gives a complete equipment list and itemized costs. Equipment costs are vendor quotations after review of the specifications in Appendix G. The installed cost for each equipment is determined by a multiplying factor between 3 to 5 which varies with the nature of the equipment, time and effort required for installation and nature of the job. This method of estimation is accurate to within ±30 percent. To determine the total capital cost, the costs for land, design, engineering, construction management, fee for profit and contingency are added to the installed cost. From Table 5-4 the estimated capital cost for this system is $600,000 in December 1976 dollars.

Annual Operation and Maintenance Costs

Table 5-5 gives a breakdown of the various elements making up the operation and maintenance costs. EPA has specifically instructed that energy costs be excluded from operation and maintenance costs and be shown as a separate item. This system combined with the phase separation system will need a total of 5 operators. For purposes of this cost analysis, the total operator costs are split 40 percent and 60 percent between the two systems giving a total of $37,440 for the calcination system. All the other items in Table 5-5 are based on the cost element data furnished to JEC by EPA (4). The annual operating cost for the system is $144,000.

TABLE 5-3

EQUIPMENT LIST AND INSTALLED COST

CALCINATION PROCESS

Item No.	Description	Quantity	Equipment or Unit Cost	Multiplying Factor	Total Installed Cost
1	Holding Tank	1	$ 6,000	3	$ 18,000
2	(2) Feed Pumps	2	2,000	3	6,000
3	Centrifuge	1	10,000	4	40,000
4	Rotary Kiln Calciner	1	100,000	2	200,000
5	Cyclone	1	8,600	4	34,400
6	(2) Scrubbing Liquid Recirculating Pumps	2	2,000	3	6,000
7	Wet Scrubber	1	14,500	4	58,000
8	(2) Flue Gas Pumping Fans	2	1,800	3	5,400
9	Stack	1	9,000	4	36,000
	TOTALS:		$ 153,900		$ 403,800 Say 400,000

TABLE 5-4

CAPITAL COST ESTIMATE - (± 30%)

ITEM	COST
Installed Equipment Cost (Table 5-7)	$ 400,000
Land	5,000
Design Engineering	40,000
Construction Management and Fee	40,000
	$ 485,000
Contingency 20%	97,000
TOTAL CAPITAL COST:	$ 582,000
	Say $ 600,000

TABLE 5-5

ESTIMATED ANNUAL OPERATION and MAINTENANCE COST

ITEM	COST
Direct Labor (1) Two Operators @ $9/hour	$ 37,440
Supervision and Administrative (2)	18,720
Chemicals Polymer 140 kg @ 70¢/kg	100
Maintenance 4% of Capital	24,000
Taxes and Insurance 4% of Capital	24,000
Disposal of Solids	39,740
	$ 144,000

(1) Phase separation system and calcination system together need 5 operators as follows; Day Shift (Two), Evening Shift (One), Night Shift (One), Replacement (One)

(2) 50% Direct Labor

Energy Costs

The proposed system consumes a total of 75 kw/hr of electrical power of which a major portion is consumed in the operation of the calciner. Natural gas at the rate of 34 standard cubic meters/hr (SCM/hr) is required to satisfy the heat requirements of the calciner. Table 5-6 is an itemized list of all energy costs giving a total of $40,734 per year.

Value of Benefits Derived

The oil content of the waste streams is low, hence the dollar recovery or energy contributed by oil is small. The evaporation of water results in reduced disposal costs. The total dollar value of benefits is $57,320 per year (Table 5-7).

Conclusions on Cost Analysis

Table 5-8 is a summary of the cost analysis for calcination for a 32,000 cu m/day (200,000 BPSD) refinery. The capital cost is $600,000. The operation and maintenance costs are $144,000, energy cost $41,000 and the value of benefits derived is $57,000. The net annual costs after amortizing the capital at 10 percent over 10 years is $225,034; say $225,000. The product cost is 19 mills per cubic meter.

5.3 Benefits' Analysis

The two major benefits of calcination for waste Streams 12 through 15 is the reduction of residual oils to acceptable levels, and calcination of metals and other potentially hazardous substances into a more stable form. Oil, by definition, is a potentially hazardous substance and hence its reduction will detoxify the waste streams.

Table 5-9 is a summary of the benefits of the calcination system.

5.4 Environmental and Safety Aspects

The proposed calcination system will not contribute to any air, water or land pollution. Included in this section is a brief description of the environmental aspects.

TABLE 5-6

ENERGY COSTS AND USAGE (ANNUAL)

Electric Power	75 kw/hr @ $.03/kw/hr	= $ 19,710
Natural Gas	34 scm/hr @ $2/28.4 scm	= 21,024
	TOTAL:	$ 40,734

TABLE 5-7

VALUE OF BENEFITS DERIVED (ANNUAL)

Energy Contributed by Residual Oil	55 MT(2)	= $ 2,750
Reduced Disposal Costs	(10,914)[1]	= 54,570
	TOTAL:	$ 57,320

(1) at $5/MT

(2) $50/MT or $8/barrel

TABLE 5-8

COST ANALYSIS SUMMARY

I T E M	COST
Capital Cost (Table 5-4) $600,000	$
Operation and Maintenance Cost (Table 5-5)	144,000
Energy Costs and Usage (Table 5-6)	40,734
Value of Benefits Derived (Table 5-7)	(57,320)
Net Operating Cost	$ 127 414
Amortization of Capital Cost @ 10%, 10/yrs	97,620
Capital Recovery Factor 0.1627	
NET ANNUAL COST:	$ 225,034
Treatment Cost on Wet Basis	$11.93/MT
Treatment Cost on Dry Basis	$26.59/MT
Product Cost Impact	19 mills/Cu. M

TABLE 5-9

BENEFITS' ANALYSIS

Benefit Item	Treatment		Remarks
	Before	After	
Detoxification*	64 MT	8 MT	88% Destruction
Volume Reduction	18, 862 Cu. M	7, 948 Cu. M	58% Volume Reduction
Product Recovery	—	—	Oil is Burned
Energy Recovery	None	56 MT	Oil as Energy
Disposal Cost Reduction	$ 94, 310	$ 39, 740	Reduction in Cost $54, 570

---

* Based on removal/destruction of oil

Air Pollution

Ninety-five percent of the particulates' emission would be removed by cyclone and wet scrubber, reducing the concentration of the particulates in the exit gas to less than 578×10^{-6} kg/cu m (36×10^{-6} lbs/ft^3). It is proposed to use low sulfur fuel oil or natural gas to minimize the sulfur dioxide pollution. Any residual hazardous components in the gases can be removed by adding clays to the calciner which form complex alumino silicates having low leachability characteristics.

Water Pollution

A significant portion of the oil present in the feed to the calcination system is removed in the centrifuge and burned in the rotary kiln calciner. A portion of the centrate is used as the scrubbing liquid absorbing the air pollutants and any hazardous vapors. The balance of the centrate and scrubber effluents is discharged to the refinery wastewater treatment plant.

Safety

Calcination process functions as a closed system and no toxic vapors are released that could cause alarm or danger to the safety and health of workers.

6.0 INCINERATION SYSTEM

6.1 Incineration

The costs for incineration of waste streams from petroleum refining operations has been developed to compare with the costs of resource recovery and calcination. The phase separation system was utilized for streams 1 through 10 (See Table 6-1) and the calcination system for streams 12 through 15 (See Table 6-1). Hence, to compare costs, the incineration system costs must be developed for the same two groups of waste streams.

All waste streams except the ones excluded in the next paragraph are amenable to incineration in the same kind of incineration. Hence, in this section we developthe design and cost estimates for a single incinerator with the capacity for all the candidate waste streams from a 32,000 cu m/day (200,000 bbl/day) refinery to compare costs with the phase separation and calcination systems, the costs of incineration for the two groups of waste streams have been prorated based on the total feed rate and the heat value in each stream.

Five of the 17 waste streams are not candidates for incineration for various reasons. HF alkylation sludge (stream 11) and leaded tank bottoms (stream 7) could release toxic lead and fluoride emissions, respectively. Kerosene filter clays (stream 9) contain high percentage of inerts (92 percent) and hence are not a candidate for incineration. Coke fines and FCC fines are products of high temperature combustion and need no further treatment.

6.2 Selection of Incinerator

JEC has selected fluidized bed incinerator as the optimum choice, after evaluation of ten different incineration systems discussed in a report titled "Incineration in Hazardous Waste Management." (7) Fluidized bed incinerator is currently in use in two major petroleum refineries. It provides high heat transfer efficiency due to excellent mixing. High temperatures of incineration cause the oil phase to evaporate, which must be burned by providing stable combustion conditions provided by a fluidized bed incinerator. Fluidized bed has a simple design concept requiring no moving parts in the combustion zone and a compact design due to high heating rate per unit volume. Last, but not least, fluidized bed incinerator can handle liquids, slurries and solids equally well.

TABLE 6-1

CANDIDATE STREAMS FOR INCINERATION

Stream No.	Waste Stream	Waste Quantity MT/yr	Oil MT/yr	Water MT/yr	Solids MT/yr
1.	Slop Oil Emulsion Solids	2300	1104	920	276
2.	Silt From Storm Water Runoff	562	22	140	400
3.	Exchanger Bundle Cleaning Sludge	182	20	96	66
4.	API Separator Sludge	1803	407	956	440
5.	Non-Leaded Tank Bottoms	5083	3263	900	920
6.	Crude Tank Bottoms	29	14	4	11
7.	Leaded Tank Bottoms	NA	NA	NA	NA
8.	Dissolved Air Floatation Skimmings	13230	1650	10850	730
9.	Kerosine Filter Clays	NA	NA	NA	NA
10.	Lube Oil Filter Clays	2636	577	132	1927
Sub Total	Comparable to Phase Separation System	25825	7057	13998	4770
11.	Neutralized HF Alkylation Sludge	NA	NA	NA	NA
12.	Spent Lime From Boiler Feedwater	14200	45	8378	5777
13.	Waste Bio Sludge	1258	4	1094	160
14.	Once Through Cooling Water Sludge	3380	15	845	2520
15.	Cooling Tower Sludge	24	0	18	6
Sub Total	Comparable to Calcination System	18862	64	10335	8463
16.	FCC Catalyst Fines	NA	NA	NA	NA
17.	Coke Fines	NA	NA	NA	NA
	Total	44687	7121	24333	13233

Incinerator Description

The basic fluidized bed incinerator is shown in Figure 6-1. The bed is essentially a vessel containing inert granular particles, such as sand. Blower-driven air enters at the bottom and proceeds vertically through the bed, agitating or fluidizing it, and causing it to behave in a nature similar to a dense liquid mass. Wastes are injected pneumatically, mechanically, or by gravity into the bed. Rapid and relatively uniform mixing of wastes and bed material occurs.

In the combusiton process, heat transfer occurs between the bed materials and the injected waste materials. Typical bed temperatures are in the range of 760° - 870°C (1400° 1 1600°F). Due to the high heat capacity of the bed material, the heat content of the fluidized bed is approximately 142,000 kg - cal./m^3 (16,000 Btu/ft^3), which is about three orders of magnitude greater than the heat capacity of flue gases in typical incinerators operating in the same temperature range. Heat from combustion is transferred back to the bed material. Solid materials remain in the bed until they have become small and light enough to be carried off with the flue gas as a particulate. Collected ash is disposed in a sanitary landfill.

Gas velocity, bed diameter, bed temperature, waste type, and composition are important in designing a fluidized bed incinerator. Due to waste particle size constraints, gas velocities are usually low, around 1.5 to 2.1 meters (5-7 ft.) per second. With present design technology, bed diameters are limited to 15.3 meters (50 ft.) or less. Bed depths range from 38 centimeters (15 in.) to a few meters. Certain wastes are presized before feeding. For adequate combustion, predrying of wastes is necessary. The use of recycled combustion gases in such a drying system recovers waste heat, thus reducing auxiliary fuel input and costs. For start-up and for conditioning of the bed, an auxiliary burner system is recommended.

As with most other incineration techniques, fluidized bed combustion generates particulate and/or gases which require air pollution controls prior to emission to the atmosphere. Wet scrubbers have been recommended to be effective in reducing particulate emissions. The method used to control gaseous pollutants depends on the particular combusiton products. Normally, no odors and little nitrogen oxide is prodiced from fluidized bed combustion, due to relatively low gas temperatures and excess air requirements.

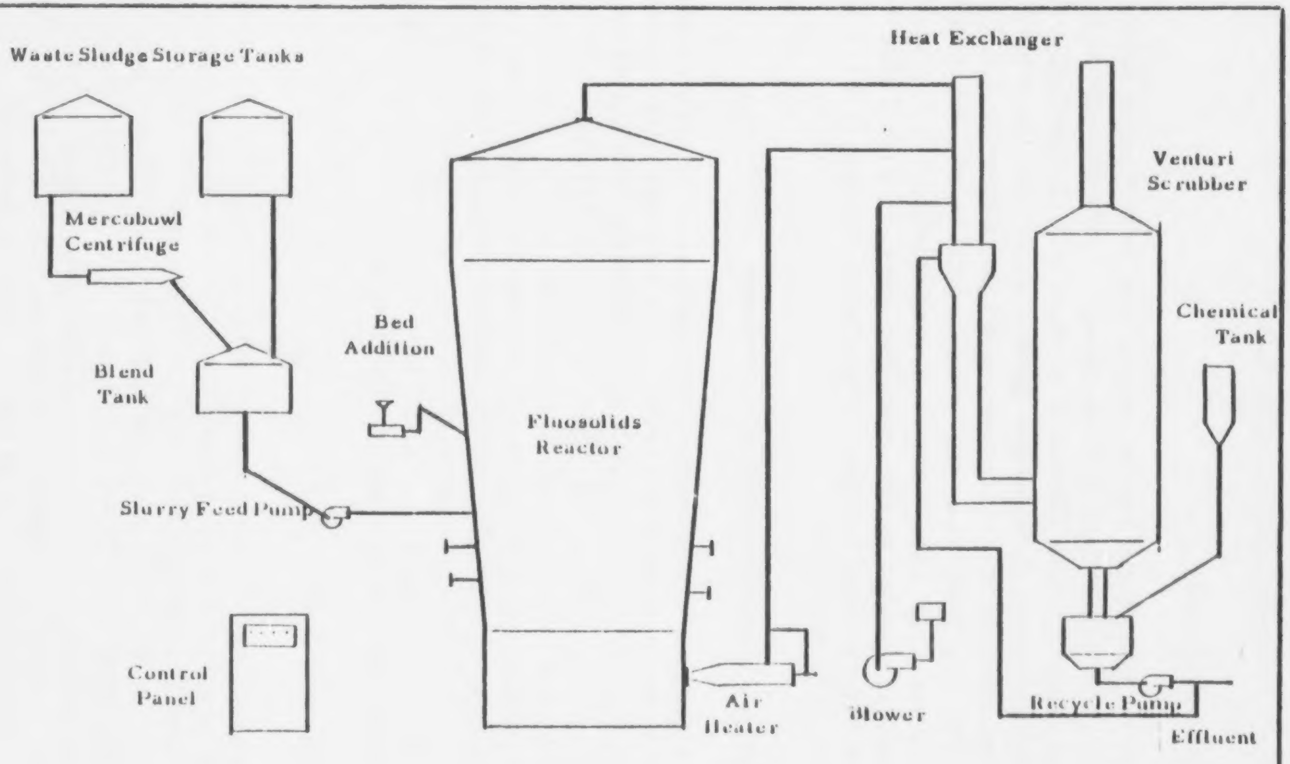

Waste Sludge Storage Tanks
Mercobowl Centrifuge
Blend Tank
Slurry Feed Pump
Control Panel
Bed Addition
Fluosolids Reactor
Air Heater
Blower
Heat Exchanger
Venturi Scrubber
Chemical Tank
Recycle Pump
Effluent

FIGURE 6-1

FLUIDIZED BED INCINERATOR
(With Sand Bed)

6.3 Cost Analysis

The basis of estimate for the incineration system is included in Appendix H. The major pieces of equipment as part of the waste incinerator are itemized in Table 6-2.

Capital Costs

The incinerator system capital costs are based on detailed estimates. hence costs for individual pieces of equipment are not available. The incinerator system (Items 4 through 12) is normally supplied by the manufacturer on a single quoted price for the whole system. The estimated cost for equipment and installation is $1,200,000 (Table 6-2). To determine the total capital cost, the costs for land, design engineering, construction management, fee for profit and contingency are added to the installed cost. From Table 6-4 the estimated capital cost for the incinerator system is $1,800,000 in December 1976 dollars.

Annual Operation and Maintenance Costs

Table 6-4 gives a breakdown of the various elements making up the operation and maintenance costs. EPA has specifically instructed that energy costs be excluded from operation and maintenance costs and be shown as a separate item. The incineration system will need an operator each shift, plus one replacement for a total of four. It is assumed that the operators will be shared with other systems and hence the cost attributable to the incineration system is for two operators. All other items in Table 6-4 are based on the cost element data furnished to JEC by EPA (4). The annual operating cost is $200,000 for the incineration system.

Energy Costs (Table 6-5)

The proposed incineration system needs 1 million kw/yr of electrical energy and 17,640 million kilo calories/yr of heat energy. Requirements do not include the available heat in the waste streams in the form of oil. This has been given credit in the next item, Value of Benefits Derived. The power costs are divided between the two groups of streams in proportion to the quantity of water in each feed. Streams 1 through 10 require 60 percent of the total electric power and heat requirements. The annual energy costs for Streams 1 through 10 is $60,000, for Streams 12 through 15 is $40,000, for a total of $100,000.

TABLE 6-2

EQUIPMENT LIST AND INSTALLED COST INCINERATION SYSTEM

Item No.	Description	Quantity
1.	Pumps	2
2.	Holding Tanks	2
3.	Mixers	2
4.	Fluidizing Air Blower	1
5.	175 HP Motor	1
6.	Start-up Burner for Preheating	1
7.	Slurry Feed Pump	1
8.	Fluidizing Reactor 8'0" Bed Diameter	1
9.	Gas-to-Gas Heat Exchanger	1
10.	Fuel Pumps	2
11.	Venturi Scrubber	1
12.	Initial Sand Bed	—
13.	All Necessary Instrumentation	—
14.	All Necessary Concrete, Structural Steel Pipe and Duct Work	—
	Installed Equipment Cost:	$ 1, 200, 000

TABLE 6-3
CAPITAL COST ESTIMATE

(± 30%)

ITEM	TOTAL
Installed Equipment Cost (Table 6-2)	$ 1,200,000
Land - 0.8 Hectares	10,000
Design and Engineering	180,000
Construction Management and Fee	120,000
Sub Total:	$ 1,510,000
Contingency	302,000
Total Capital Cost:	$ 1,812,000
	Say: $ 1,800,000

TABLE 6-4
ESTIMATED ANNUAL OPERATION AND MAINTENANCE (3)

ITEM	TOTAL
Direct Labor (1) Two Operators @ $9/hr	$ 37,440
Supervision and Administrative (2)	18,720
Maintenance 4% of Capital	72,000
Taxes and Insurance 4% of Capital	72,000
Cost of Solids Disposal	105,000
	305,160
	Say: $ 305,000

(1) One operator during day shift and 1/2 operator each during evening and night shifts.

(2) 50 percent of direct labor.

(3) Operating Hours 8760.

TABLE 6-5

ENERGY COSTS AND USAGE
OPERATING HOURS 8760

ITEM	TOTAL	PRORATED FOR Streams[1] 1 thru 10	PRORATED FOR Streams[2] 12 thru 15
Electric Power 1 Million kw/year	$ 30,000	$ 18,000	$ 12,000
Heat Requirements[3] 70,000 Millions of Btu/yr	70,000	42,000	28,000
TOTALS:	$100,000	$ 60,000	$ 40,000

TABLE 6-6

VALUE OF BENEFITS DERIVED
ANNUAL

ITEM	TOTAL	PRORATED FOR Streams (1) 1 thru 10	PRORATED FOR Streams (2) 12 thru 15
Heat Requirements of Incineration Provided by Oil in Waste Stream	$ 70,000	$ 65,000	$ 5,000
Excess Heat[4]	106,000	106,000	-0-
Reduced Disposal Costs (5)	115,000	105,000	115,000
TOTALS:	$291,000	$ 276,000	$ 15,000

(1) Streams included in Phase Separation System are approximately 60% of the total waste feed in terms of quantity and water content.

(2) Streams included in Calcination System are approximately 40% of the total feed in terms of quantity and water content.

(3) Distributed proportional to water content which is in the ratio of 60:40, price $2/Million Btu (see Table 6-1). (4) Excess heat is the heat value of oil in the waste stream at 18,000 Btu/lb with an assumed value of 50¢/M Btu after satisfying the heat requirements of incineration, (5) at 5$/MT.

Value of Benefits Derived

Table 6-6 is a summary of the benefits derived. The heat required for the incineration system and provided by the waste streams is given a value of $2/mm Btu, the same as for energy costs. The available excess heat has been given a value of $0.50 m m Btu, since energy will be lost during transportation and heat transfer. Incineration reduces the total quantity of wastes to be disposed by landfill by the amount of oil and water in the waste stream. The total dollar value of benefits for Streams 1 through 10 is $276,000, for Streams 12 through 15 is $15,000, for a total of $291,000.

Conclusions on Cost Analysis

Table 6-7 is a summary of the cost analysis for the incineration system for applicable waste streams for a 32,000 cu m/day (200,000 BPSD) refinery. The capital cost is $1,800,000, the operation and maintenance costs are $200,000, energy costs $100,000 and value of benefits derived is $291,000. The net annual costs after amortization of capital at 10 percent over 10 years is $79,000 for Streams 1 through 10, $225,000 for Streams 12 through 15, for a total net annual cost of $304,000. The product cost impact of incineration for Streams 1 through 10 is 12 mills/cu m and for Streams 12 through 15 is 23 mills/cu m for a total of 35 mills/cu m.

TABLE 6-7

COST ANALYSIS SUMMARY
INCINERATION

ITEM	TOTAL	Streams 1 thru 10	Streams 12 thru 15
Operation & Maintenance Costs Table 6-4	$ 305,000	$ 183,000	$ 122,000
Energy Costs and Usage Table 6-5	100,000	60,000	40,000
Value of Benefits Derived Table 6-6	(291,000)	(276,000)	(15,000)
Net Operating Costs:	$ 115,000	$ 33,000	$ 147,000
Amortization of Capital Cost @ 10%, 10 yrs. Capital Recovery Factor .1627	295,000	175,000	120,000
Net Annual Costs:	$ 409,000	$ 142,000	$ 267,000
Capital Cost:	$1,800,000	$1,080,000	$ 720,000
Cost per MT Wet Basis	$9.15	$5.50	$14.20
Cost per MT Dry Basis	$30.90	$29.77	$31.55
Product Cost Impact	35 mills/ Cu m	12 mills/ Cu m	23 mills/ Cu m

7.0 LAND DISPOSAL

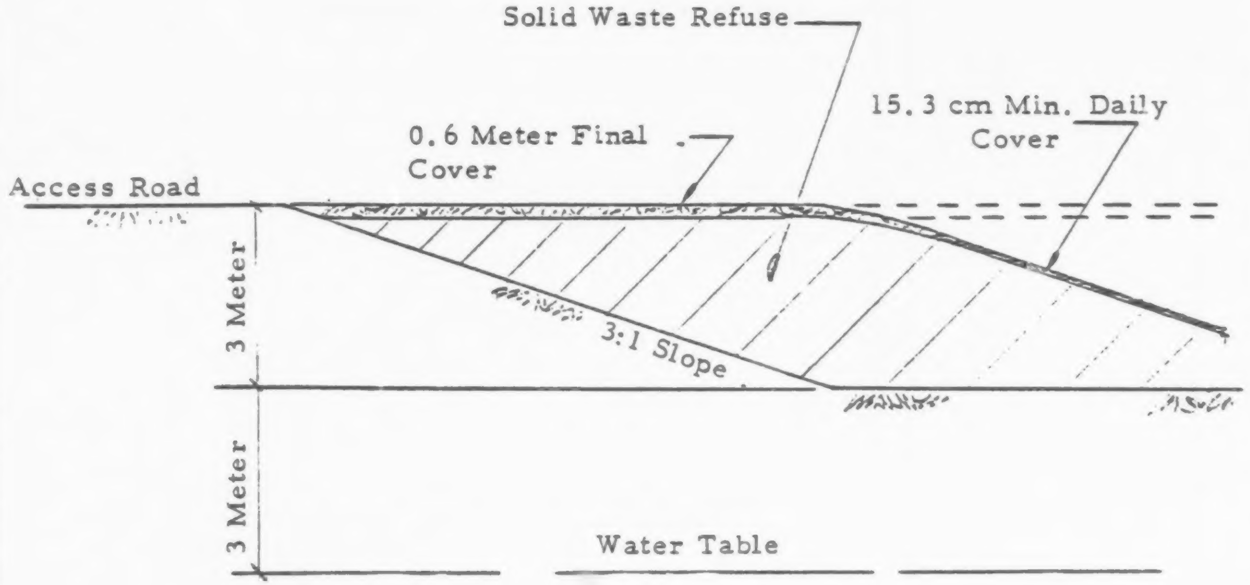
7.1 Sanitary Landfill

To develop costs for sanitary landfill comparable to the costs for phase separation system and calcination system the total costs to landfill all waste streams from the refining operation is separated into two groups viz, Streams 1 through 10 and Streams 12 through 15. The total costs for operation of a typical landfill is first determined followed by determination of cost per ton and then the appropriate costs for each group of waste streams. Stream 11, HF alkylation sludge, may contain soluable toxic substances and hence is not acceptable in a sanitary landfill.

This section determines the cost of disposal in a standard sanitary landfill by the individual refining company. Figure 7-1 and 7-2 show plan and section of a typical sanitary landfill. The trench method of operation is used, with balanced cut and fill to minimize costs for earthwork, and disposal of excess spoils. Dikes are provided around the perimeter of the site for proper drainage, with oiled access roads. A fire protection system around the perimeter with fire hydrants at 152 meter (500 feet) intervals is provided. Since the landfill is an inter-company operation, no scales are necessary. A portable chain link fence to guard the landfill area in use is included in the analysis.

Method of Operation

In the trench method of sanitary landfilling, a long, narrow excavation is made in the earth and the soil removed from this excavation is stockpiled. Wastes are then deposited at one end of the excavation on the sloped end of the trench. The refuse is spread on a rather shallow inclination (usually about 3 horizontal to 1 vertical) and then compacted by the placement compaction equipment used at the site. At the end of the day's operation the compacted layers of refuse are covered with a 15.3 cm (6 inches) layer of soil taken from the stockpile of material removed in the original excavation. When the entire trench has been filled with refuse, a final 0.6 meter (2 feet) cover layer is placed over the completed deposit of refuse. The length and depth of the trench are variable from site to site. The choice of equipment for use on a landfill site will depend on a number of factors: size of overall operation, types of wastes deposited, water and soil conditions at the site. The most common choice of equipment is a Cat 58, a dump truck and dragline.

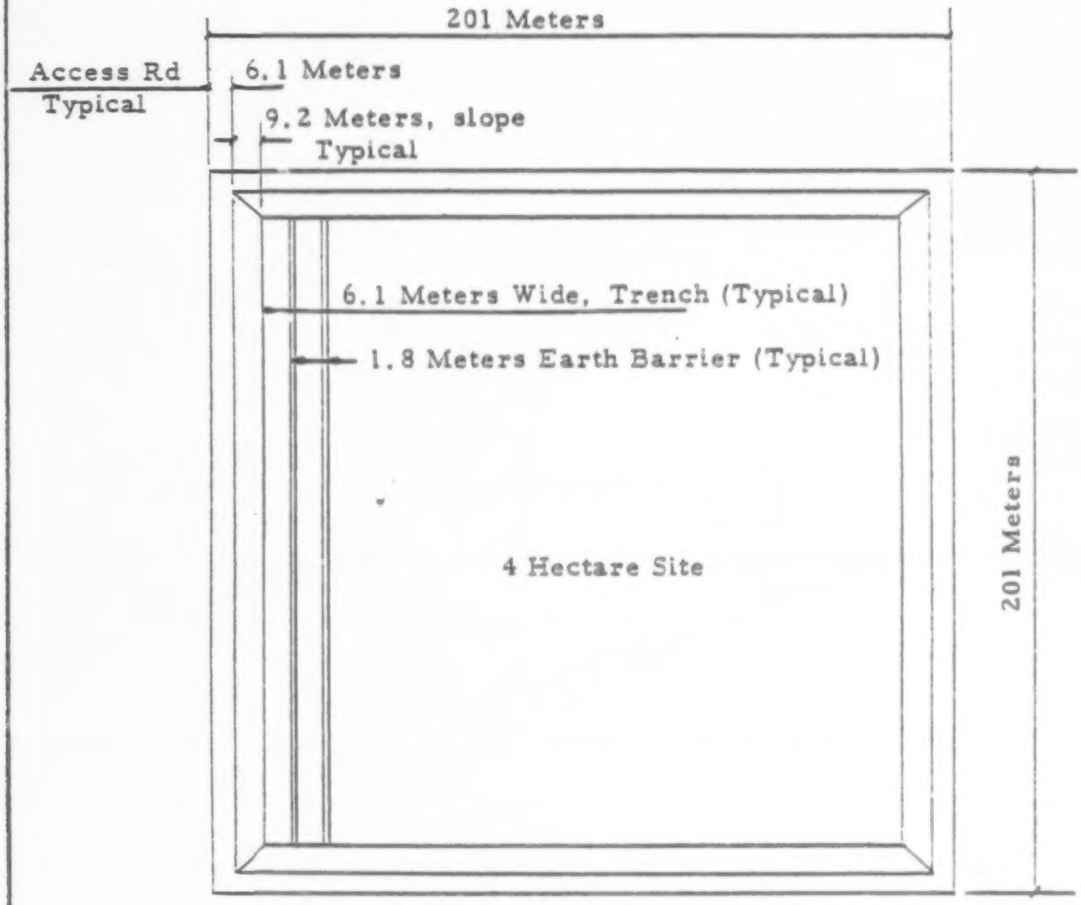

Solid Waste Refuse
15.3 cm Min. Daily Cover
0.6 Meter Final Cover
Access Road
3 Meter
3:1 Slope
3 Meter
Water Table

TYPICAL SECTION
(Trench Method)

Note: Excess spoil spread over landfill and surrounding area.

FIGURE 7-1

SANITARY LANDFILL


201 Meters
Access Rd
Typical
6.1 Meters
9.2 Meters, slope
Typical
6.1 Meters Wide, Trench (Typical)
1.8 Meters Earth Barrier (Typical)
4 Hectare Site
201 Meters

PLAN
(No Scale)

FIGURE 7-2

SANITARY LANDFILL

Capital Costs

Table 7-1 gives the capital costs associated with a thirty-three hectare landfill site owned and operated by an individual refinery. This site is sufficient for 10 years of operation. The total estimated capital cost is $900,000 in December 1976 dollars.

Annual Operation and Maintenance Costs

Table 7-2 gives a breakdown of the various elements making up the operation and maintenance costs. The landfill is operated five days a week, eight hours a day. The annual operating cost is $87,760.

Energy Costs

The estimated costs for diesel fuel to run the various pieces of equipment is $8,000/year. (See Table 7-3)

Conclusions on Cost Analysis

Table 7-5 is a summary of the cost analysis with a breakdown for Streams 1 through 10 and 12 through 15. The total annual costs for Streams 1 through 10 is $140,491, for Streams 12 through 15 is $101,699, for a total of $242,190. Table 7-4 shows that 52,000 MT of solid wastes can be disposed in a 33 hectare landfill site. Hence, a 33 hectare site will last for 10 years for the candidate groups of waste streams generating 26,057 MT/year and 18,862 MT/year, respectively. The average cost, based on a total waste quantity of 44,919 MT/year and an annual cost of $242,190, is $5.39 per MT. The product cost impact is 21 mills/cubic meter.

7.2 Chemical Landfill

The costs for disposing the waste streams in a chemical landfill are to be estimated for cost comparisons with other treatment systems. We have utilized the design criteria and specifications outlined in the reference "Chemical Waste Land Disposal Facility Demonstration Grant Application SW-87d." (8)

The chemical landfill is lined with compacted colloidal clay, and covered with a 20 mil PVC liner. A primary leachate collection system is installed with no leachate treatment, but includes a leachate recirculation system. An adsorbent such as a regular sponge is used to adsorb excess liquids. Figures 7-3 and 7-4 show a typical dike section and plan for a chemical landfill.

TABLE 7-1
CAPITAL COSTS FOR SANITARY LANDFILL
33 HECTARE SITE

ITEM	COST
Land Thirty-Three Hectares	$ 400,000
Equipment	150,000
Fire Protection System (Portable)	40,000
Paved Roads (with residual oil from refinery)	160,000
Site Preparation @ 2000/acre = $5000/Hectare	160,000
Portable Chain Link Fence	8,000
	$ 918,000
Say:	$ 900,000 (1)

TABLE 7-2
ESTIMATED ANNUAL OPERATION AND MAINTENANCE COSTS (3)

ITEM		COST
Direct Labor	Two Operators @ $9/hour	$ 37,440
Supervision and Administrative (2)		18,720
Maintenance	4% of Capital	14,000
Taxes and Insurance	4% of Capital	14,000
Monitoring Costs	(required by State Water Quality Control Boards)	3,600
		$ 87,760

(1) Contingency is not normally added to landfill cost estimates.
(2) 50% of direct labor
(3) Operating Hours 2080

TABLE 7-3

ENERGY COSTS AND USAGE

ITEM	COST
Diesel to Drive Equipment	$ 8,000
TOTAL	$ 8,000

TABLE 7-4

QUANTITY OF WASTES DISPOSED IN A FOUR-HECTARE LANDFILL

(See Figure 7-2)

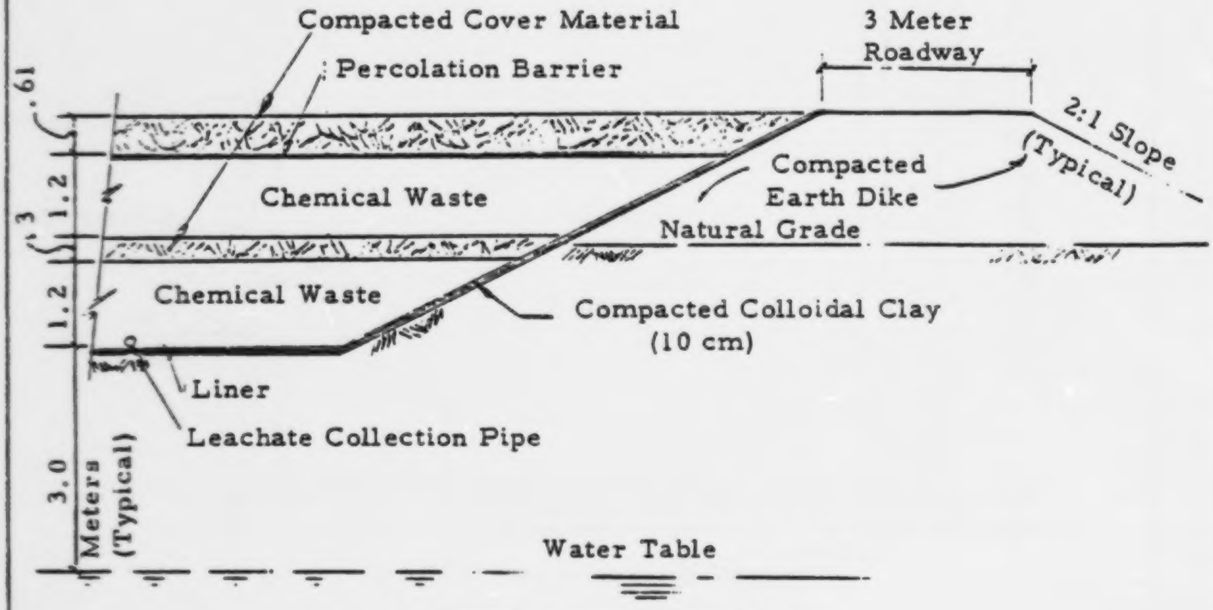
ITEM		
Total Land Area -		39,200 Sq. M
Perimeter Access Road -		4,725 Sq. M
3:1 Slope for 3 m Deep Trench		3,564 Sq. M
1.8 m Earth Barrier (one every 6 m)		80,195 Sq. M
Net Area Available for Landfill		22,865 Sq. M
Total Depth of Trench -	3.3M	
Final Earth Cover -	-0.6M	
Intermediate Earth Cover -	-0.3M	
Net Available Depth	2.4M	
Volume Available for Waste Disposal	=	54,876 Cu M
Density of Waste	=	950 Kg/Cu M
Total Quantity of Wastes Disposed	=	52,000 MT (115,000 lbs)

TABLE 7-5

COST ANALYSIS SUMMARY SANITARY LANDFILL*

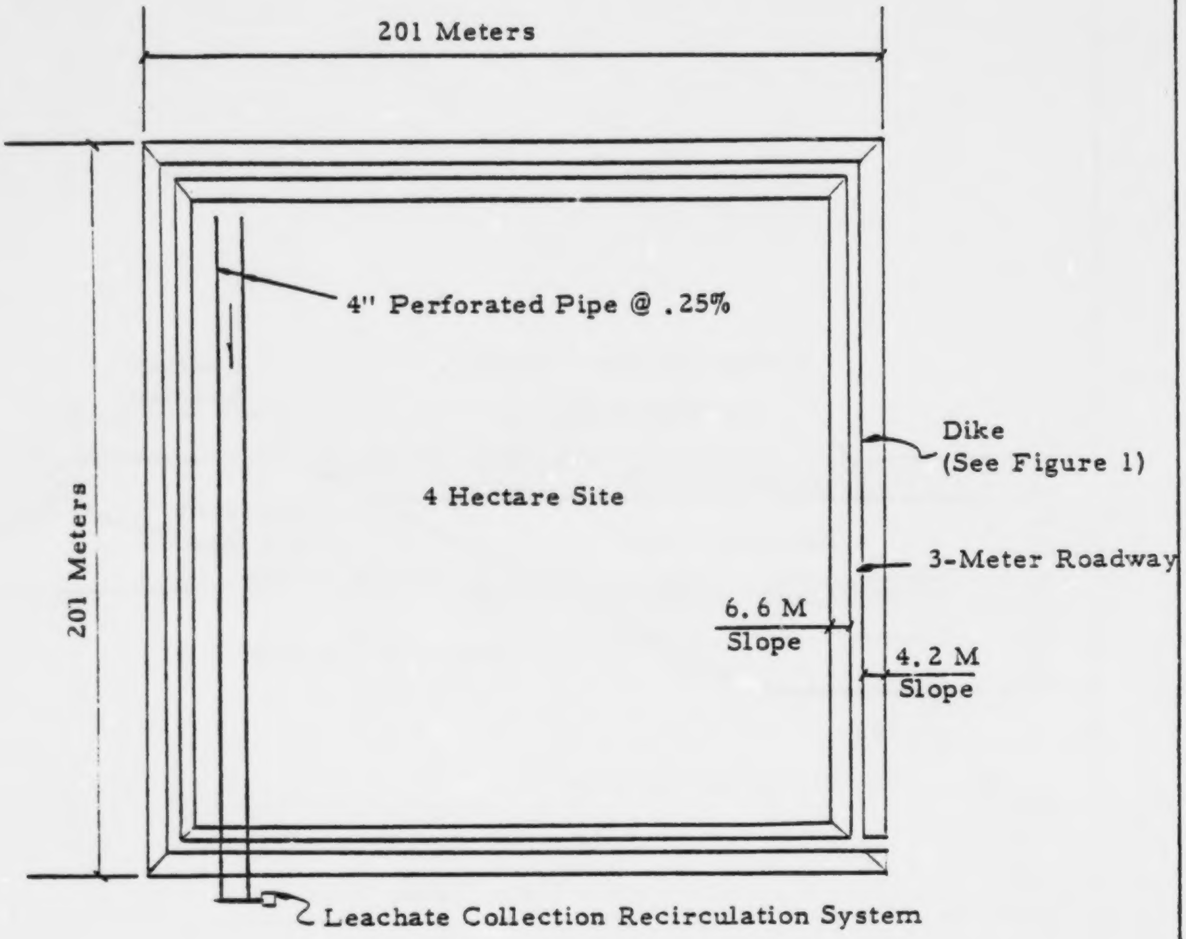
ITEM	Total	Streams 1 thru 10	Streams 12 thru 15
Operation and Maintenance (7-2)	87,760	50,909	36,851
Energy Costs (7-3)	8,000	4,640	3,360
Value of Benefits	None	None	None
Net Operating Costs:	95,760	55,549	40,211
Amortization of Capital 10 yrs @ 10%			
Capital Recovery Factor .1627	146,430	84,942	61,488
Total Costs:	242,190	140,491	242,190
	900,000	522,000	101,699
Costs per ton - Wet Basis	$5.39	$5.39	$5.39
Costs per ton - Dry Basis	$17.60	$28.23	$11.59
Product Cost Impact	21 mills/ Cu M	12 mills/ Cu M	9 mills/ Cu M

*The costs are distributed between the two groups of streams in proportion to the waste quantity. Streams 1 through 10 represent 58% of the total.


Compacted Cover Material
Percolation Barrier
3 Meter
Roadway
2:1 Slope
(Typical)
.61
1.2
.3
1.2
Chemical Waste
Compacted
Earth Dike
Natural Grade
Chemical Waste
Compacted Colloidal Clay
(10 cm)
Liner
Leachate Collection Pipe
3.0
Meters
(Typical)
Water Table

TYPICAL DIKE SECTION

FIGURE 7-3
CHEMICAL LANDFILL


201 Meters
201 Meters
4" Perforated Pipe @ .25%
Dike
(See Figure 1)
4 Hectare Site
3-Meter Roadway
6.6 M
Slope
4.2 M
Slope
Leachate Collection Recirculation System

PLAN
(No Scale)

FIGURE 7-4
CHEMICAL LANDFILL

The selection of 20 mil PVC liner is based on conversations with Mr. Haxo of Matriceon and liner manufacturers. Both Mr. Haxo and the liner manufacturers felt that with the available data, the selection of a 20 mil PVC liner is appropriate to prepare cost estimates required for cost comparisons.

The chemical landfill is very similar to the sanitary landfill in the method of construction. The trench method of construction and associated items are discussed in detail in Section 7.1 and hence not repeated here. A safe site selection with the objectives of protecting the groundwater, surface water and air quality is imperative. Primary protection of ground and surface waters is provided by the liner system discussed above. The quantity of wastes that can be disposed in a 4 hectare chemical landfill is the same as sanitary landfill (See Table 7-4), i.e., 52,552 MT.

Capital Costs

Table 7-6 gives the capital costs for an eighty-acre landfill site owned and operated by an individual refinery. This site is sufficient for 10 years of operation. The total estimated capital cost is $2,600,000 in December 1976 dollars.

Annual Operation and Maintenance Costs

Table 7-7 gives a breakdown of the various cost elements for 40 hours/week, 52-week operation. The annual operating cost is $300,000.

Energy Costs

The estimated costs for diesel fuel and electric power to operate the chemical landfill is $10,000/year. (See Table 7-8)

Conclusions on Cost Analysis

Table 7-9 is a summary of the costs incurred in a chemical landfill with a breakdown of costs for Streams 1 through 10 and 12 through 15. The total annual costs for Streams 1 through 10 is $431,000, for Streams 12 through 15 is $302,000, for a total of $733,000. The eighty-acre site will last for 10 years for the candidate groups of waste streams generating 26,057 MT/year and 18,862 MT/year, respectively. The average cost based on a total waste quantity of 44,919 MT/year and an annual cost of $733,000 is $16.31 per metric ton. The product cost impact is 63 mills/cubic meter. For HF

TABLE 7-6

CAPITAL COSTS FOR CHEMICAL LANDFILL EIGHTY-ACRE SITE

ITEM	COST
Land	$ 400,000
Equipment	150,000
Fire Protection System (Portable)	40,000
Paved Roads (with residual oil from refinery)	160,000
Site Preparation @ $5,000/Hectare	160,000
Portable Chain Link Fence	8,000
Liner - In Place @ $3.10/sq m	570,000
Membrane (percolation barrier)	570,000
Clay Seal @ $1.55/sq m	280,000
Leachate Collection System	300,000
Sub Total:	$ 2,638,000 (1)
Say:	$ 2,600,000

(1) Contingency is not normally added to landfill cost estimates.

TABLE 7-7

ESTIMATED ANNUAL OPERATION AND MAINTENANCE COSTS
OPERATING HOURS 2080

ITEM		COST
Direct Labor	3 Operators @ $9/hour	$ 56,160
Supervision and Administrative (1)		28,080
Maintenance	4% of Capital	105,500
Taxes and Insurance	4% of Capital	105,500
Monitoring Costs	(required by State Water Resources Control Boards)	3,600
		$ 298,840
Total:	Say:	$ 300,000

TABLE 7-8

ENERGY COSTS AND USAGE

ITEM		COST
Diesel to Drive Equipment	@ 13¢/liter	$ 8,000
Electric Power for	@ .03¢/kwh	2,000
Total:		$ 10,000

---

(1) 50% of direct labor

TABLE 7-9

COST ANALYSIS SUMMARY[*]
CHEMICAL LANDFILL

ITEM	Total	Streams 1 thru 10	Streams 12 thru 15
Operation and Maintenance Costs (Table 7-7)	$ 310,000	180,000	120,000
Energy Costs (Table 7-8)	10,000	6,000	4,000
Value of Benefits	None	None	None
Net Operating Costs:	$ 310,000	186,000	124,000
Amortization of Capital 10 yrs @ 10%			
Capital Recovery Factor .1627	$ 423,000	245,000	178,000
	$2,600,000	1,560,000	1,040,000
Costs per ton Wet Basis	$16.31	$16.54	$16.01
Costs per ton Dry Basis	$53.27	$86.61	$$34.38
Product Cost Impact mills/Cu M	63	36	27

[*] All costs are distributed between the two groups of streams in proportion to the waste quantity. Streams 1 through 10 present approximately 58% of the total.

alkylation sludge the cost per metric ton on a dry basis is $41.95 with a product cost impact of 1 mill/cu m.

8.0 COST COMPARISON

8.1 Capital Investment

Table 8-1 provides a summary of the capital investment required for each group of waste streams. For Streams 1 through 10 the capital investment costs for chemical landfill and the proposed phase separation system are comparable. Sanitary landfill requires the least capital investment

For Streams 12 through 15 the proposed calcination system has a lower capital cost than chemical landfill, but is comparable to incineration. Sanitary landfill requires the least capital investment for Streams 12 through 15. For Stream 11, HF alkylation sludge capital costs for the recommended phase separation system followed by lime precipitation system is comparable to chemical landfill.

8.2 Effect on Product Cost

This report contains a significant number of cost elements and hence requires proper perspective prior to reaching any conclusions. The disposal costs per metric ton of waste includes the value of benefits derived and hence is not directly comparable to similar cost figures for another industry.

Table 8-1 provides a summary of the total annual costs and the effect on product costs of a 32,000 cu m/day (200,000 BPSD) refinery. The recommended systems for Streams 1 through 15 cost a total of 32 mills*/cu m (5.3 mills/bbl) of crude processed. The effect on product cost for incineration is comparable to the recommended system, whereas, a chemical landfill is almost twice as costly. It must be noted that the cost comparisons are based on budget estimates of systems which are only conceptual. Hence prior to making any specific recommendations, Jacobs suggests that additional work be carried out on the proposed treatment systems to assess the technical feasibility. Also the quantity of oil available for resource recovery in each of the 17 waste streams must be verified.

8.3 Break-Even Cost Analysis

The price of crude oil has increased exponentially in the last six years from $2/bbl to $14/bbl. Further, the average price of domestic oil is about $8/bbl, whereas, imported oil has reached $14/bbl. Hence,

---

*1 mill is 1/10 of a cent

TABLE 8-1

COST COMPARISONS

	Recommended System	Incineration	Landfill	
			Sanitary	Chemical
Capital Costs				
Streams 1 through 10	$ 1,512,000	$ 1,080,000	$ 540,000	$ 1,560,000
Stream 11	55,000	NA	NA	52,000[1]
Streams 12 through 15	600,000	720,000	360,000	1,040,000
Cost Per MT of Waste (Wet Weight)				
Streams 1 through 10	$ 6.90	$ 5.50	$ 5.39	$ 16.54
Stream 11	48.20	NA	NA	16.31
Streams 12 through 15	11.93	14.20	5.39	16.01
Effect on Product Cost[2]	mills/cu m (mills/bbl)	mills/cu m (mills/bbl)	mills/cu m (mills/bbl)	mills/cu m (mills/bbl)
Streams 1 through 10	15 (2)	12 (2)	12 (2)	36 (6)
Stream 11	3 (0.5)	NA	NA	1 (0.2)
Streams 12 through 15	19 (3)	23 (4)	9 (1)	27 (4)
Total:	37 (6)	35 (6)	21 (3)	64 *10.2)

NA - The candidate process not applicable due to technical reasons.

(1) - A rough estimate. It is not practical to construct a chemical landfill for just one stream.

(2) - Computed from total annual cost and total annual production.

it is impractical to predict future oil prices except to state that if domestic oil price controls are removed, then the price of domestic crude oil will match the world oil prices.

Benefits' Analysis in the report are based on a price of \$50/MT (\$8/bbl) for the recovered oil. The market price at which one can realize a break-even situation for the various systems discussed in this report are as follows:

Streams 1 through 10	\$ 73/MT (\$ 12/bbl)
Stream 11	\$ 342/MT (\$ 54/bbl)
Streams 12 through 15	\$ 3419/MT (\$ 547/bbl)

9.0 EXISTING INSTALLATIONS

9.1 Information Search

EPA required JEC to furnish information on the various unit processes and systems currently utilized by the petroleum refining industry to recover materials or energy and/or detoxification. JEC made a complete search utilizing the following avenues:

Literature Search
Technology Consultants
Industry Survey

The following pages discuss the results of the above inquiry.

Literature Search

OSW provided JEC with extensive literature on the subjects of solid wastes' technology and hazardous waste disposal, which were reviewed. In addition, JEC spent time at various libraries in Southern California; such as California Institute of Technology, University of Southern California, and University of California at Los Angeles. JEC found no systems currently in use or under development for recovery of energy or materials and/or detoxification of waste streams from petroleum refining operations. Some of the pertinent literature obtained by this search may be of use at a future date.

Technology Consultants

JEC reviewed the Arthur D. Little report, "Physical, Chemical and Biological Treatment Techniques for Industrial Wastes," (2) to identify any petroleum refining facilities utilizing the unit processes. In addition, JEC met twice with the Technology Consultants to review unit processes and to determine their current applications. The above meetings did not disclose any current or planned application of any unit processes or systems for recovery or reuse in the petroleum refining operation. JEC did find that a process called Basic Extractive Sludge Treatment (B.E.S.T.) developed by Resources Conservation Company (RCC) has potential for application to refinery waste streams after certain modifications. Appendix F includes a discussion of the BEST process and estimated costs for application of the process for recovery of oil from waste streams 1 through 10. The data and discussions are limited to information supplied by RCC.

Industry Survey

JEC made a list of industry contacts to develop information on processes, both prototype and pilot plant. currently utilized in the petroleum refining industry for recovery or reuse of materials and energy. American Petroleum Institute (API) suggested that API contact the industry on behalf of JEC and EPA. API mailed our letter of inquiry to thirty industry sources and received responses from seventeen. The responses are tabulated in Table 9-1, the numbers in each column representing the positive responses. A quick review of Table 9-1 confirms the earlier findings that industry is not currently practising any resource or energy recovery in a systematic manner.

API claims that many refineries are currently extracting oil from wastes containing high quantities of oil such as tank bottoms and API separator sludge by variangle mixers and phase separation in heated vessels. These procedures, API claims, may remove as much as 80 percent of the oil in the waste stream. API also indicates that recycling of waste materials with high oil content is carried out by blending oily waste materials with the feed to cokers, thermal cracking units or crude tankage.

Land farming of refinery waste streams containing oil is finding wide acceptance in the industry and appears to be quite practical and environmentally compatible. The costs for land farming are in the range of $5 to $10 per MT which is comparable to the costs for sanitary landfill.

Conclusions

Based on literature search, consultations with technology consultants and industry survey, JEC has determined that there are no full-scale operating installations, laboratory or pilot scale facilities in the petroleum refining industry to recover energy or materials from the seventeen waste streams in a continuous and systematic manner. It must be noted that the Petroleum Refining Industry, as a whole, attempts to reduce the quantity of oil in the waste streams, when it is economically feasible and attempts to recover oil from those waste streams containing a large percentage of oil.

TABLE 9-1

PETROLEUM REFINING INDUSTRY - CURRENT SOLID WASTE DISPOSAL PRACTICES*

Stream No.	Waste Stream	Filtration	Centrifugation	Aerobic Digestion	Anaerobic Digestion	Other	Landfill	Land Farming	Incineration
1.	Slop Oil Emulsion Solids					1 A	3	4	1
2.	Silt From Storm Water Runoff					1 B		3	
3.	Exchange Bundle Cleaning Sludge						2	2	
4.	API Separator Bottoms		1				5	7	
5.	Non-Leaded Product Tank Bottoms	2					4	4	
6.	Crude Tank Bottoms					2 C	5	5	
7.	Lead Tank Bottoms					1 D	2	4	
8.	Dissolved Air Floatation Float		2			1 A	2	3	
9.	Kerosene Filter Clays						3	4	2
10.	Lube Filter Clays					1 E	2		
11.	Neutralized HF Alkylation Sludge						3		
12.	Spent Lime From Boiler Feed Water Treatment					1 B	3	4	2
13.	Waste Bio Sludge	1	2	3	1	1 F	5	2	
14.	Cooling Water Separator Sludge						2		
15.	Cooling Tower Sludge						5	2	
16.	FCC Catalyst Fines					1 G	6	2	
17.	Coke Fines					1 H	3	1	

A Catalytic Cracking B Disposal to River C Evaporation and Settling Pond D Lead Oxidation E Solvent Extraction
F Flocculation and Dissolution G Sell it H Oxidation

* The numbers in each column represent the positive responses.

REFERENCES

1. "Assessment of Hazardous Waste Practices in the Petroleum Refining Industry," by Jacobs Engineering Co., Pasadena, California, prepared for the Office of Solid Waste, EPA.

2. "Physical, Chemical and Biological Treatment Techniques for Industrial Wastes," by Arthur D. Little, Inc., Boston, Massachusetts, prepared for the Office of Solid Waste, EPA.

3. "Macro & Semimicro Qualitative Inorganic Analysis," by Arthur Vogel, 4th Edition, a text book.

4. "Cost Element Data," furnished by the Office of Solid Waste, EPA.

5. "Industrial Solvents," Reinhold Publishing Co. New York.

6. "Dangerous Properties of Industrial Materials," by Irving Sax, 4th Edition, 1974.

7. "Incineration in Hazardous Waste Management," prepared by OSW, EPA in 1975.

8. "Chemical Waste Land Disposal Facility Demonstration Grant," Application SW 87d.

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APPENDIX A

MATRIX

Enclosed is the matrix referred to in Section 2. 2 to evaluate applicable unit processes for the 17 waste streams.

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TABLE A-1

UNIT PROCESS

WASTE STREAM

	Air Stripping	Ammonia Stripping	Carbon Adsorption	Centrifugation	Distillation	Electrodialysis	Evaporation	Filtration	Flocculation	Flotation	Freeze Crystal	HGMS	Ion Exchange	Liquid Ion Exchange	Other Adsorption	Resin Adsorption	Reverse Osmosis	Sedimentation	Solvent Extraction	Steam Stripping	Ultrafiltration	Calcination	Catalysis	Chlorinolysis	Electrolysis	Hydrolysis	Microwave	Neutralization	Oxidation	Ozonolysis	Precipitation	Reduction	Activated Sludge	Aerated Lagoon	Anaerobic Digestion	Composting	Enzyme Treatment	Trickling Filter	Stabilization Pond	Crushing & Grinding	Cyrogenics	Dissolution	Steam Distillation
Crude Bottoms	6	6	5	X	X	2	7	X	X	7	X	7	2	5	5	7	2	●	X	7	2	X	X	5	2	X	8	6	10	10	7	5	3	3	3	X	X	3	3	4	6	4	7
Leaded Bottoms	6	6	5	X	X	2	7	X	X	7	X	7	2	5	5	7	2	●	X	7	2	X	10	5	2	X	8	6	X	10	7	5	3	3	3	X	X	3	3	4	6	4	7
Product Bottoms	6	6	5	X	X	2	7	X	X	7	X	7	2	5	5	7	2	●	X	7	2	X	10	5	2	X	8	6	10	10	7	5	3	3	3	X	X	3	3	4	6	4	7
API Sludge	6	6	5	X	X	5	X	X	X	X	X	9	5	5	5	X	5	X	X	X	5	X	10	5	5	X	8	6	10	10	X	5	10	3	3	X	X	3	3	4	6	4	X
Neutr. HF Sludge	6	6	5	X	5	5	X	X	X	5	9	X	2	5	5	X	5	X	X	X	5	X	10	5	5	5	8	●	10	10	X	5	3	3	3	X	X	3	3	4	6	4	X
Kerosene Filter Clay	6	6	5	1	5	2	1	1	1	1	1	1	5	1	1	1	2	1	1	1	2	X	10	5	1	5	8	6	10	10	1	5	3	3	3	X	X	3	3	4	6	X	X
Once-Thru-Cooling	6	6	5	X	5	5	X	X	X	●	9	X	5	5	5	X	5	X	X	X	5	X	10	5	5	5	8	6	10	10	X	5	3	3	3	X	X	3	3	4	6	4	X
DAF Float	6	6	5	X	X	5	X	X	X	X	X	9	5	5	5	X	5	X	X	X	5	X	10	5	5	X	8	6	10	10	X	5	10	3	3	X	X	10	3	4	6	4	X
Slop Oil Emulsion	6	6	5	X	X	5	X	X	X	X	9	9	5	5	5	X	5	X	X	X	5	X	X	5	5	X	8	6	10	10	X	5	3	3	3	X	X	3	3	4	6	4	X
Spent Lime	6	6	5	X	5	5	X	X	X	5	9	X	5	5	5	X	5	X	X	X	5	X	10	5	5	5	8	X	10	10	X	5	3	3	3	X	X	3	3	4	6	4	X
Cooling Tower Sludge	6	6	5	X	5	5	X	X	X	X	9	X	5	5	5	X	5	X	X	X	5	X	10	5	5	5	8	6	10	10	X	5	3	3	3	9	9	3	3	4	6	4	X
Exch. Bundle Sludge	6	6	5	X	5	5	X	X	X	X	9	X	5	5	5	X	5	X	X	X	5	X	10	5	5	5	8	6	10	10	X	5	3	3	3	X	X	3	3	4	6	4	X
Waste Bio Sludge	6	6	5	X	5	5	X	X	X	X	9	6	5	5	5	X	5	X	X	X	5	X	10	5	5	5	8	6	10	10	X	5	10	●	X	X	X	X	3	4	6	4	X
Storm Water Silt	6	6	5	X	5	5	X	X	X	5	9	X	5	5	5	X	5	X	X	X	5	X	10	5	5	5	8	6	10	10	X	5	10	3	3	X	X	3	3	4	6	4	X
FCC Catalyst Fines	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	X	10	5	1	5	8	6	10	10	1	5	3	3	3	9	9	3	3	6	6	X	X
Coke Fines	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	X	10	5	1	5	8	6	10	10	1	5	3	3	3	9	9	3	3	6	6	X	X
Lube Oil Filter Clays	6	6	5	1	5	2	1	●	1	5	9	7	2	1	5	1	2	1	X	1	2	X	10	5	2	5	8	6	10	10	1	5	3	3	3	10	X	3	3	4	6	4	X

X: Candidate Treatment Process for the Waste Stream in Question

1: Treatment Process Applicable to Liquid Waste Streams

2: Treatment Process Applicable to Aqueous Waste Streams (Solutions)

3: Biological Treatment Process Not Effective Due to High Content of Solids or Oil and Grease

4: Treatment Process Applicable to Solids

5: Physical or Chemical Process Ineffective Due to High Content of Solids or Impurities

6: Unit Process Not Applicable Due to the Absence of Material Being Treated

●: Waste Stream is Product of the Treatment Process.

7: High Concentration of Waste Material

8: Process Not Applicable for Large Quantities

9: Quantity of Wastes is Insignificant for Treatment By Unit Process.

10: Unknown

EVALUATION MATRIX

APPENDIX B

COMPUTATION OF GENERATION RATE

This section develops the method for computation of waste generation rate for Tables 2-4 and 2-5 of the text.

The last row of Table 39 of the assessment study (PB 259 097) gives the median generation rate in metric tons per year, dry weight, for 1,000 BPSD of crude capacity for each of the 17 waste streams. Dry weight corresponds to the total weight less weight of water and weight of oil.

For example, let us consider the waste stream Slop Oil Emulsion solids. Table 39 indicates dry weight generation rate as 1.38 metric tons/year. It also indicates in the previous two rows that the percentages of water and oil in the waste stream are 40 and 48 respectively. Hence to determine the wet weight generation rate, divide 1.38 by 12 percent to arrive at 11.5 shown in column 3 of Table 2-4.

Appendix J of the assessment study states that the following waste streams are generated less frequently than once a year.

Non-Leaded Tank Bottoms	Once every 10 years
Leaded Tank Bottoms	Once every 6.5 years
Crude Tank Bottoms	Once every 3 years

To determine the wet generation rate per year for these streams, the same method as for slop oil must be followed, and the resulting number divided by the frequency of occurrence.

For example, Table 39 indicates the generation rate of 46 metric tons per year for non-leaded product tank bottoms. Wet generation rate prior to dividing by frequency of occurrence is 254 (46/0.181) and after is 25.4 (254/10) shown on Table 2.4 of the text.

Table 39 shows that the capacity for the following unit processes are less than the crude processing capacity of 200,000 BPSD. These are FCC Catalytic Cracker, HF Alkylation, Lube Oil and Coke Fines. The attached table computes the actual capacities for these units in a typical 200,000 BPSD refinery. To determine the waste generation from these streams, the actual capacity computed in Table 1 is used. For example, Table 39 shows the generation rate for FCC Fines is 5.45. The corresponding wet weight is 5.46 (5.45/9.9979) MT/year. Table 1 shows the catalytic cracker capacity as 67,800 BPSD, hence the total wet weight is (5.46/1000) x 67,800 = 371 metric tons/year. This number and the generation rate corresponding to the crude processing capacity of 200,000 BPSD are shown in Tables 2-4 and 2-5.

TABLE 39

RANGES AND MEDIANS OF CONCENTRATIONS OF POTENTIALLY HAZARDOUS CONSTITUENTS OF REFINERY WASTE STREAMS

(Concentration levels in mg/kg (dry weight); median levels in parentheses)
(Totals in metric tons (dry weight) per 1000 BPSD of crude capacity unless otherwise noted)

Number of Samples		3	2	9	4	12	5	3	2	5
Parameters	Typical Background*	Once-Through cooling water sludge	Exchanger bundle cleaning sludge	Slop oil emulsion solids	Cooling tower sludge	API/Separator Sludge	Dissolved Air Flotation Float	Kerosene Filter Clays	Lube Oil Filter Clays	Waste Biosludge
Phenols	0.54 1)	2.0-2.1 (2.0)	8.-18.5 (13.3)	5.7-127 (15)	0.6-7.0 (3.5)	3.8-156.7 (13.6)	3.0-210 (6.5)	2.0-25.2 (2.6)	0.05-6.4 (3.2)	1.7-10.2 (4.5)
Cyanide	2.6 1)	0.01-0.74 (0.11)	0.0004-3.3 (1.7)	0.000012-52.5 (0.001)	0.0005-17.2 (0.1)	0.00006-51.4 (0.001)	0.01-1.1 (0.28)	0.00025-0.0007 (0.0005)	0.01-0.22 (0.12)	0001-19.5 (0.001)
Selenium (Se)	0.5	0,1-10.4 (1.6)	2.4-52 (27.2)	0.1-8.8 (1.0)	0,01-2.4 (0.015)	0.005-7.6 (0.001)	0.1-4.2 (2.0)	0.01-26.1 (9.6)	0.1-2.1 (1.1)	0.01-5.4 (0.01)
Arsenic (As)	5	0.1-18 (5.4)	10.2-11 (10.6)	2.5-18.5 (7.4)	0.7-21 (8.2)	0.1-32 (6.2)	.05-10.5 (2.0)	0.09-14 (2.2)	0.05-1.4 (0.7)	1.0-6.0 (3.8)
Mercury (Hg)	0.1	0.42-1.34 (0.51)	0.14-3.6 (1.9)	0.005-12.25 (0.59)	0.004-3.35 (0.09)	0.04-6.2 (0.4)	0.07-0.89 (0.27)	0.0004-0.05 (0.0004)	0.04-0.33 (0.19)	0.004-1.28 (0.18)
Beryllium (Be)	6	0.013-0.63 (0.24)	0.05-0.34 (0.20)	0.002-0.38 (0.0025)	0.001-0.2 (0.0013)	0.0012-0.24 (0.0025)	0.0012-0.25 (0.0025)	0.025-0.35 (0.2)	0.025-0.5 (0.26)	0.0013-.002 (0.0013)
Vanadium (V)	140	15.-57. (39.)	0.7-50 (25.)	0.12-75 (25)	0.12-35 (7.8)	1.0-48.5 (9.8)	0.05-0.15 (0.05)	13.2-42 (35)	0.5-65 (33)	.012-5.0 (.05)
Chromium (Cr)	200	16.6-103 (63)	310-311 (311)	0.1-1750 (525)	181-1750 (554)	0.1-6790 (253)	28-260 (140)	0.9-25.8 (2.88)	1.3-45 (23.2)	0.05-475 (300)
Cobalt (Co)	25	5.5-11.2 (6.3)	0.2-3.0 (1.6)	0.1-82.5 (10)	0.38-7 (1.3)	0.1-26.2 (5.7)	0.13-67.5 (2.0)	0.4-2.3 (0.62)	1.3-5. (3.2)	0.05-1.4 (0.2)
Nickel (Ni)	80	20.5-39. (35.)	61-170 (116)	7.5-160 (50)	0.25-50 (6.8)	0.25-150.4 (19.3)	0.025-15 (0.025)	0.025-15 (0.04)	0.25-22 (11.1)	0.013-11.3 (0.025)
Copper (Cu)	200	57.4-180 (153)	67-75 (71)	8.5-420 (48)	13-363 (50)	2.5-550 (18.6)	0.05-21.3 (7.0)	0.4-9.875 (11.4)	0.5-8.0 (4.3)	1.5-11.5 (9.5)
Zinc (Zn)	200	93-233 (125)	91-297 (194)	60-2725 (250)	118-1100 (675)	25-6596 (298)	10-1825 (85)	6.6-35. (25)	0.5-115. (57.6)	3.3-225 (122)
Silver (Ag)	0.1	0,24-1,3 (0.5)	0.0007-0.01 (0.005)	0.013-20,1 (0.4)	0.01-1.6 (0.28)	0.05-3 (0.45)	0,0013-2,8 (0.25)	0.02-0.7 (0.5)	0.013-1.0 (0.5)	0.1-0.5 (0.3)
Cadmium (Cd)	0,2	0.0024-1.0 (0.003)	1.0-1.5 (1.3)	0.025-2 (0.19)	0.06-0.6 (0.3)	0.024-3.0 (0.42)	0.0025-0.5 (0.005)	0.19-0.4 (0.25)	0.025-1.5 (0.76)	0.16-0.54 (0.3)
Lead (Pb)	16	17.2-138. (57.)	0.5-155 (78)	0.25-580 (28.1)	1.2-89. (38)	0.25-1290 (26)	2.3-1250 (7.5)	4.25-12 (8.3)	0.25-2.3 (1.28)	1.2-17 (5.0)
Molybdenum (Mo)	1	0,05-33 (2.5)	1-12 (6.5)	0.25-20 (5)	0.25-2.5 (1.1)	0.25-60 (5)	0.025-2.5 (0.05)	0.012-8.8 (0.025)	0.025-0.05 (0.038)	0.25-2.5 (2.5)
Ammonium Salts (as NH_4)	No Value 1)	0,1-13 (6.)	5-11 (8)	1,5-44 (8)	0,07-14 (6.3)	0,05-30 (6.5)	8,5-210 (9)	(0.01)	(2)	6,5-30 (21)
Benz-A-pyrene	0.01 1)	0.003-1.8 (0.004)	0.7-3.6 (2.2)	0.002-0.018 (0.003)	0.003-0.8 (0.004)	0.002-4.5 (0.004)	0,004 -1.75 (0.002)	1.7-1.8 (1.8)	0.02-0.2 (0.1)	0.002-0.005 (0.003)
Oil (Weight %)	2.9 1)	0.24-17.0 (0.43)	8.3-13 (10.7)	27.9-63.2 (48)	0.07-4.0 (0.44)	3,3-59.8 (22.6)	2.4-16.9 (12.5)	0.7-5.6 (3.5)	3,9-39.8 (21.9)	0.01-0.53 (0.28)
Water(Weight %)		3-45 (25)	42-64 (53)	10-74 (40)	50-88.3 (75.4)	7-98 (53)	30-99 (82)	0-16 (5)	0-99 (50)	56-95 (87)
Total Weight metric tons/yr / 1000 BPSD unit capacity		7,3-13,5 (12,6)	0,19-0,47 (0,33)	0,84-17.5 (1.38)	0,025-0,032 (0,029)	0.14-21.2 (2.2)	2.45-5.58 (3.64)	0.75-120.6 (0.93)	56.2-375. (215.6) 2)	0.23-5.0 (0.8)

(*) Average values from Table 34 unless otherwise noted

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TABLE 39 (continued)

Number of Samples	5	2	2	2	3	4	7	11
Parameters	Coke Fines	Silt from storm water runoff	Leaded Tank Bottoms	Non-leaded Product Tank Bottoms	Neutralized HF Alkylation Sludge (CaF$_2$) 6)	Crude Tank Bottoms	Spent Lime from Boiler Feedwater Treatment	Fluid Catalytic Cracker Catalyst Fines
Phenols	0.4-2.7 (2.0)	6.3-8.6 (7.5)	2.1-250 (126)	1.7-1.8 (1.8)	3.2-14.6 (8.9)	6.1-21 (15.8)	0.05-3.6 (2.1)	0.3-72 (2.1)
Cyanide	0.00025-0.001 (0.001)	.34-3.1 (1.72)	0.0008-0.001 (0.0009)	0.005-14.7 (7.4)	0.21-46 (23.1)	0.00025-0.8 (0.0012)	0.00002-1.28 (0.001)	0.01-1.44 (0.12)
Selenium (Se)	0.01-1.6 (0.01)	1.1-2.2 (1.7)	3.1-10.8 (6.95)	1.5-22.4 (12)	0.1-14 (7.1)	0.01-1 (0.03)	0.01-12.2 (0.01)	0.01-19.1 (0.01)
Arsenic (As)	0.2-10.8 (2.0)	1.0-10.0 (5.5)	63-525 (294)	0.005-0.009 (0.007)	0.05-4.5 (2.3)	5.8-53 (21.1)	0.05-2.6 (0.1)	0.05-4.0 (1.0)
Mercury (Hg)	0.0004-0.2 (0.04)	0.23-0.36 (0.30)	.19-0.94 (0.57)	0.41-0.44 (0.43)	0.05-0.09 (0.07)	0.07-1.53 (0.48)	0.004-2.73 (0.04)	0.0004-0.16 (0.0004)
Beryllium (Be)	0.0025-0.5 (0.005)	0.0012-0.0025 (0.0019)	.0025-.0025 (.0025)	.025-0.49 (0.26)	0.012-0.13 (0.07)	0.0013-0.25 (0.0026)	0.001-0.002 (.0012)	0.025-1.4 (0.5)
Vanadium (V)	400-3500 (455)	25-112 (69)	1.0-9.8 (5.4)	9.1-34.6 (21.9)	0.25-5. (2.6)	5-62 (17.4)	0.007-31.6 (0.05)	74.4-1724 (240)
Chromium (Cr)	0.02-7.5 (0.02)	32.5-675 (354)	9.0-13.7 (11.4)	12.7-13.1 (12.9)	0.75-5 (6.8)	1.9-75 (19.4)	0.025-27.9 (2.2)	12.3-190 (71)
Cobalt (Co)	0.2-9.2 (4.0)	11.0-11.3 (11.2)	26.5-71 (49)	5.9-8.2 (7.1)	0.025-0.7 (0.36)	3.8-37 (14.8)	0.002-1.3 (0.005)	0.25-37 (6.6)
Nickel (Ni)	350-2200 (580)	30-140 (85)	235-392 (314)	12.4-41 (26.7)	7.4-103 (55.2)	12.8-125 (16.2)	0.13-22.5 (2.5)	47.5-1000 (241)
Copper (Cu)	3.5-5.0 (4.0)	14.8-41.8 (28.3)	110-172 (141)	6.2-164 (85.1)	2.5-26 (14.3)	18.5-194 (65.4)	0.22-63.2 (3.8)	4.1-336 (17.5)
Zinc (Zn)	0.2-20 (14)	60-100 (230)	1,183-17,000 (9092)	29.7-541 (285)	8.6-9.5 (9.1)	22.8-425 (145)	2.0-121 (15.0)	19-170 (39)
Silver (Ag)	0.01-3.0 (.01)	0.5-0.5 (0.5)	0.05-1.7 (0.88)	0.49-0.7 (0.6)	0.12-0.25 (0.19)	0.03-1.3 (0.19)	0.05-0.7 (0.5)	0.5-3.0 (1.8)
Cadmium (Cd)	0.015-2.0 (1.0)	0.01-0.42 (0.22)	4.5-8.1 (6.3)	0.25-0.4 (0.33)	0.012-0.12 (0.07)	0.25-0.42 (0.31)	0.0012-0.3 (0.003)	0.001-0.5 (0.003)
Lead (Pb)	0.5-29 (13.0)	20.5-86 (53.3)	158-1421 (790)	12.1-37.3 (24.7)	4.5-9.6 (7.1)	10.9-338 (18.9)	0.01-7.3 (3.8)	10-195 (50)
Molybdenum (Mo)	0.1-2.5 (0.1)	6.3-7.5 (6.9)	0.5-118 (59)	0.25-18.2 (9.2)	0.0025-0.0025 (0.0025)	0.25-95 (6.3)	0.0025-0.05 (0.025)	0.5-21.6 (6.3)
Ammonium Salts (as NH$_4$)	.7	(1.0)	No Value	(0.2)	0.002-0.002 (0.002)	(2)	0.005-5.0 (0.015)	.01
Benz-A-pyrene	0.002-0.005 (0.002)	0.03-2.5 (1.27)	0.02-0.4 (0.21)	0.3-0.9 (0.6)	0.002.	0.03-0.6 (0.11)	0.002-0.002 (0.002)	0.0002-1.5 (0.005)
Oil (Weight %)	0.001-1.34 (0.001)	2.2-5.5 (3.9)	18.9-21 (20)	45.1-83.2 (64.2)	6.7-7.1 (6.9)	21-83.6 (47.4)	0.04-0.49 (0.32)	0.01-0.81 (0.21)
Water (Weight %)	(0)	20-29.7 (25)	0-0.6 (0.3)	15.4-20 (17.7)	30-78.4 (54.2)	1-20 (13.3)	5-91.8 (59)	(0)
Total Weight Metric tons/yr 1000 BPSD unit capacity	0.06-4.2 (0.28) 3)	(2.0)	0.2-1.3 (0.75)	28.6-63.4 (46.0)	12.8-30.6 (21.7) 4)	0.12-0.22 (0.17)	11.7-88.0 (28.9)	0.65-23.6 (5.45) 5)

Notes

(1) From a background refinery soil sample analyzed at Jacobs Engineering Co.

(2) Metric tons (dry weight) per 1,000 BPSD lube capacity.

(3) Metric tons (dry weight) per 1,000 BPSD coker capacity.

(4) Metric tons (dry weight) per 1,000 BPSD alkylation capacity

(5) Metric tons (dry weight) per 1,000 BPSD FCC capacity

(6) Fluoride values: 20,000-76,600 (48,300)

Table 39 of the Industry study is included here for reference. A simple equation to develop the dry weight is as follows:

$$\text{Dry Weight (DW)} = \text{Total Weight (TW)} - \text{Weight of water (WW)} - \text{Weight of Oil (WO)} = \text{TW } 1 - \frac{(\%\text{ water} + \%\text{ oil})}{100}$$

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TABLE 1

CAPACITY FOR UNIT PROCESSES

Refinery[a]	Cat Cracker Fresh · Feed		Alkylation		Lubes		Coke		
BPSD	%	bbl/d	%	bbl/d	%	bbl/d	%	t/d	bbl/d
193,000	29.5	57,000	3.7	7,200			4.66	1,800	9,000
205,000	17.8	36,500	3.7	7,600			2.20	900	4,500
186,000	45.7	85,000	12.9	24,000			4.57	1,700	8,500
186,000	41.9	78,000	15.3	28,400			2.26	840	4,200
250,000	40.0	100,000	5.4	13,500			1.72	860	4,300
177,000	21.3	37,700			1.19	2,100	1.75	620	3,100
150,000	26.7	40,000	6.5	9,700					
180,000	44.4	80,000	8.3	15,000					
180,000	41.7	75,000	6.7	12,000	9.44	17,000			
233,500	29.6	69,000	3.8	9,000	2.78	6,500	2.78	1,300	6,500
Ave.	33.9%		7.37%		4.47%		2.85%		

Hence for 200,000 BPSD crude capacity, the capacity for various unit processes is as follows:

Cat Cracker	-	67,800 BPSD
HF Alkylation	-	14,700 BPSD
Lube Processing	-	8,940 BPSD
Coke Fines	-	5,700 BPSD

[a] All U.S. refineries with crude capacities of 150,000 to 250,000 BPSD are listed.

APPENDIX C

CHARACTERIZATION OF WASTE STREAMS

The form of occurrence for each parameter in each of the 17 waste streams is outlined in the following tables.

TABLE C-1

SLOP OIL EMULSION SOLIDS

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	15	Phenols
Cyanide	.001	Cyanide
Selenium	1.0	From the Crude
Arsenic	7.4	As Arsenic
Mercury	.59	From the Crude
Beryllium	.0025	From the Crude
Vanadium	25	From the Crude
Chromium	525	As $Cr(OH)_3$
Cobalt	10	In the Oil
Nickel	50	In the Oil
Copper	48	In the Oil
Zinc	250	Carbonate
Silver	.4	From the Crude
Cadmium	.19	From the Crude
Lead	28.1	as Tetraethyl Lead (TEL)
Molybdenum	5	From the Crude
Ammonia Salts	8	Ammonium Sulfate
Benz-A-Pyrene	003	Benz-A-Pyrene
Oil %	48	Mixture of all fractions
Water %	40	
Solids %	12	Dirt, Silt, Rust, Corrosion Products

* Based on engineering judgement.

TABLE C-2

SILT FROM STORM WATER RUNOFF

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	7.5	Phenols
Cyanide	1.72	Cyanide
Selenium	1.7	Carbonates or Oxides
Arsenic	5.5	Carbonates or Oxides
Mercury	.30	Carbonates or Oxides
Beryllium	.0019	Carbonates or Oxides
Vanadium	69	Carbonates or Oxides
Chromium	354	Carbonates or Oxides
Cobalt	11.2	Carbonates or Oxides
Nickel	85	Carbonates or Oxides
Copper	28.3	Carbonates or Oxides
Zinc	230	Carbonates or Oxides
Silver	.5	Carbonates or Oxides
Cadmium	.22	Carbonates or Oxides
Lead	53.3	Carbonates or Oxides
Molybdenum	6.9	Carbonates or Oxides
Ammonia Salts	1.0	Ammonium Sulfate
Benz-A-Pyrene	1.27	Benz-A-Pyrene
Oil %	3.9	Mixture of light & heavy fractions
Water %	25	
Solids %	71.1	Sand and Silt

* Based on engineering judgement.

TABLE C-3

EXCHANGER BUNDLE CLEANING SLUDGE

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	13.3	Phenols
Cyanide	1.7	Cyanide
Selenium	27.2	Oxides or Silicates
Arsenic	10.6	Arsenic
Mercury	1.9	Oxides or Silicates
Beryllium	.20	Oxides or Silicates
Vanadium	25	Oxides or Silicates
Chromium	311	Oxides or Silicates
Cobalt	1.6	Oxides or Silicates
Nickel	116	Oxides or Silicates
Copper	71	Oxides or Silicates
Zinc	194	Oxides or Silicates
Silver	.005	Oxides or Silicates
Cadmium	1.3	Oxides or Silicates
Lead	78	As Tetraethyl Lead
Molybdenum	6.5	Oxides or Silicates
Ammonia Salts	8	Ammonium Sulfate
Benz-A-Pyrene	2.2	Benz-A-Pyrene
Oil %	10.7	Mixture of Light & Heavy Oil
Water %	53	
Solids %	36.3	Silt, Scale and Rust

* Based on engineering judgement.

TABLE C-4

API SEPARATOR SLUDGE

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	13.6	Phenols
Cyanide	.001	Cyanide
Selenium	.001	Carbonates or Hydroxides
Arsenic	6.2	As Arsenic
Mercury	.4	Carbonates or Hydroxides
Beryllium	.0025	Carbonates or Hydroxides
Vanadium	9.8	Carbonates or Hydroxides
Chromium	253	Carbonates or Hydroxides
Cobalt	5.7	Carbonates or Hydroxides
Nickel	.913	Carbonates or Hydroxides
Copper	18.6	Carbonates or Hydroxides
Zinc	298	Carbonates or Hydroxides
Silver	.45	Carbonates or Hydroxides
Cadmium	.42	Carbonates or Hydroxides
Lead	26	Lead as TEL
Molybdenum	5	Carbonate or Hydroxide
Ammonia Salts	6.5	Ammonium Sulfate
Benz-A-Pyrene	.004	Benz-A-Pyrene
Oil %	22.6	Tar
Water %	53	
Solids %	24.4	Sand, Silt, Rust & Corrosion Products

* Based on engineering judgement.

TABLE C-5

NON-LEADED TANK BOTTOMS

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	1.8	Phenols
Cyanide	7.4	Cyanide
Selenium	12	Oxide
Arsenic	.007	Arsenic
Mercury	.43	Oxide
Beryllium	.26	Oxide
Vanadium	21.9	From Oil
Chromium	12.9	Oxide
Cobalt	7.1	Oxide
Nickel	26.7	Oxide
Copper	85.1	Oxide
Zinc	285	From Oil
Silver	.6	Oxide
Cadmium	.33	Oxide
Lead	24.7	Gasoline Additives, TEL
Molybdenum	9.2	Oxide
Ammonia Salts	.2	Ammonium Sulfate
Benz-A-Pyrene	6	Benz-A-Pyrene
Oil %	64.2	Mixture of Heavy & Light Fractions
Water %	17.7	
Solids %	18.1	Rust and Corrosion

* Based on engineering judgment.

TABLE C-6

CRUDE TANK BOTTOMS

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	15.8	As Phenols
Cyanide	.0012	As Cyanide
Selenium	.03	Oxide
Arsenic	21.1	As Arsenic
Mercury	.48	Oxide
Beryllium	.0026	Oxide
Vanadium	17.4	From Crude Oil
Chromium	19.4	Oxide
Cobalt	14.8	Oxide
Nickel	16.2	Oxide
Copper	65.4	Oxide
Zinc	145	From Crude Oil
Silver	.19	Oxide
Cadmium	.31	Oxide
Lead	18.9	Oxide
Molybdenum	6.3	Oxide
Ammonia Salts	2	Ammonium Sulfate
Benz-A-Pyrene	.11	Benz-A-Pyrene
Oil %	47.4	Crude Oil
Water %	13.3	
Solids %	39.3	Rust, Corrosion Products, Sand

* Based on engineering judgment.

TABLE C-7

LEADED TANK BOTTOMS

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	126	Phenols
Cyanide	.0009	Cyanide
Selenium	6.95	Oxide
Arsenic	294	As Arsenic
Mercury	.57	Oxide
Beryllium	.0025	Oxide
Vanadium	5.4	From Crude Oil
Chromium	11.4	Oxide
Cobalt	49	Oxide
Nickel	314	Oxide
Copper	141	Oxide
Zinc	9090	From Crude Oil
Silver	.88	Oxide
Cadmium	6.3	Oxide
Lead	790	Tetra Ethyl Lead
Molybdenum	59	Oxide
Ammonia Salts	-	Ammonium Sulfate
Benz-A-Pyrene	.21	Benz-A-Pyrene
Oil %	20	Refined Oil
Water %	.3	
Solids %	79.7	Rust and Corrosion Products

* Based on engineering judgment.

TABLE C-8

DAF FLOAT

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	6.5	Phenols
Cyanide	.28	Cyanide
Selenium	2.0	Metal Silicate Complex
Arsenic	2.0	As Arsenic
Mercury	.27	In Aqueous State, Generally very Low Concentrations
Beryllium	.0025	Metal Silicate Complex
Vanadium	.05	in Oil
Chromium	140	As Hydroxide
Cobalt	2.0	Metal Silicate Complex
Nickel	.025	Metal Silicate Complex
Copper	7.0	Metal Silicate Complex
Zinc	85	Metal Silicate Complex
Silver	.25	Metal Silicate Complex
Cadmium	.005	Metal Silicate Complex
Lead	7.5	in Oil
Molybdenum	.05	in Oil
Ammonia Salts	9	Ammonium Sulfate
Benz-A-Pyrene	.002	Benz-A Pyrene
Oil %	12.5	Mixture of Light & Heavy Fractions
Water %	82	
Solids %	5.5	Fine Silts and Sands

* Based on engineering judgment.

TABLE C-9

KEROSENE FILTER CLAYS

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	2.6	Phenols
Cyanide	.0005	Cyanide
Selenium	9.6	Clay Silicate Complex
Arsenic	2.2	Arsenic
Mercury	.0004	Clay Silicate Complex
Beryllium	.02	OrganicallyBound in Oil
Vanadium	35	Organically Bound in Oil
Chromium	2.88	Organically Bound in Oil
Cobalt	.62	Organically Bound in Oil
Nickel	.04	Organically Bound in Oil
Copper	11.4	Organically Bound in Oil
Zinc	25	Organically Bound in Oil
Silver	.5	Organically Bound in Oil
Cadmium	.25	Organically Bound in Oil
Lead	8.3	In Oil as TEL
Molybdenum	025	Clay Silicate Complex
Ammonia Salts	.01	Ammonium Sulfate
Benz-A-Pyrene	1.8	Benz-A-Pyrene
Oil %	3.5	Light Fraction - Kerosene
Water %	5	
Solids %	95.5	Clay

* Based on engineering judgment.

TABLE C-10

LUBE OR FILTER CLAYS

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	3.2	Phenols
Cyanide	.12	Cyanide
Selenium	1.1	In Clay Silicate Complex
Arsenic	.7	Arsenic
Mercury	.19	In Clay Silicate Complex
Beryllium	.26	
Vanadium	.33	Organically Bound in Oil
Chromium	23.2	Organically Bound in Oil
Cobalt	3.2	Organically Bound in Oil
Nickel	11.1	Organically Bound in Oil
Copper	4.3	Organically Bound in Oil
Zinc	57.8	Organically Bound in Oil
Silver	.5	Organically Bound in Oil
Cadmium	.76	Organically Bound in Oil
Lead	1.28	Organically Bound in Oil
Molybdenum	.038	Organically Bound in Oil
Ammonia Salts	2	Ammonia Sulfate
Benz-A-Pyrene	.1	Benz-A-Pyrene
Oil %	21.9	Heavy Fraction
Water %	5	
Solids %	73.1	Clay(Bentonite or Fullers Earth)

* Based on engineering judgment.

TABLE C-11

NEUTRALIZED HF ALKYLATION SLUDGE

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	8.9	Phenols
Cyanide	23.1	Cyanide
Selenium	7.1	
Arsenic	2.3	Arsenic
Mercury	.07	Fluorides, Soluble
Beryllium	.07	Fluorides, Soluble
Vanadium	2.6	Fluorides, Soluble
Chromium	2.8	Fluorides, Soluble
Cobalt	.36	Fluorides, Soluble
Nickel	55.2	Fluorides. Soluble
Copper	14.3	Fluorides, Lightly Soluble
Zinc	9.1	Fluorides, Soluble
Silver	.19	Fluorides. Soluble
Cadmium	.07	Fluorides, Soluble
Lead	7.1	Fluorides Lightly Soluble
Molybdenum	.0025	Fluorides, Soluble
Ammonia Salts	.002	Ammonium Sulfate
Benz-A-Pyrene	.002	Benz-A-Pyrene
Oil %	6.9	Essentially Gasoline
Water %	54.2	
Solids %	38.9	Calcium Carbonate

* Based on engineering judgment.

TABLE C-12

SPENT LIME

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	2.1	Phenols
Cyanide	.001	Cyanide
Selenium	.01	Carbonates or Oxides
Arsenic	.1	Carbonates or Oxides
Mercury	.04	Carbonates or Oxides
Beryllium	.0012	Carbonates or Oxides
Vanadium	.05	Carbonates or Oxides
Chromium	2.2	Carbonates or Oxides
Cobalt	.005	Carbonates or Oxides
Nickel	2.5	Carbonates or Oxides
Copper	3.8	Carbonates or Oxides
Zinc	15.0	Carbonates or Oxides
Silver	.5	Carbonates or Oxides
Cadmium	.003	Carbonates or Oxides
Lead	3.8	Carbonates or Oxides
Molybdenum	.025	Carbonates or Oxides
Ammonia Salts	.015	Ammonium Sulfate
Benz-A-Pyrene	.002	Benz-A-Pyrene
Oil %	.32	
Water %	59	
Solids %	40.68	$CaCO_3$

* Based on engineering judgment.

TABLE C-13

WASTE BIO SLUDGE

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	4.5	Phenols
Cyanide	.001	Cyanide
Selenium	.01	Carbonates or Oxides
Arsenic	3.8	Carbonates or Oxides
Mercury	.18	Carbonates or Oxides
Beryllium	.0013	Carbonates or Oxides
Vanadium	.05	Carbonates or Oxides
Chromium	300	
Cobalt	.02	Carbonates or Oxides
Nickel	.025	Carbonates or Oxides
Copper	9.5	Carbonates or Oxides
Zinc	122	Carbonates or Oxides
Silver	.3	Carbonates or Oxides
Cadmium	.3	Carbonates or Oxides
Lead	5.0	Carbonates or Oxides
Molybdenum	2.5	Carbonates or Oxides
Ammonia Salts	21	Ammonium Sulfate, Addition of Nutrients for Bio-Treatment
Benz-A-Pyrene	.003	Benz-A-Pyrene
Oil %	.28	
Water %	87	
Solids %	12.72	Waste Bio Mass

* Based on engineering judgment.

TABLE C-14

ONCE THROUGH COOLING WATER SLUDGE

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	2.0	Phenols
Cyanide	.11	Cyanide
Selenium	1.6	Oxide/Carbonate
Arsenic	5.4	As Arsenic
Mercury	.51	Oxide/Carbonate
Beryllium	.24	Oxide/Carbonate
Vanadium	39	Oxide/Carbonate
Chromium	63	As $Cr(OH)_3$
Cobalt	6.3	Oxide/Carbonate
Nickel	35	Oxide/Hydroxide
Copper	153	Oxide
Zinc	125	Oxide
Silver	.5	Oxide
Cadmium	.003	Oxide
Lead	57	from spills, as TEL
Molybdenum	2.5	Oxide
Ammonia Salts	6	Ammonium Sulfate
Benz-A-Pyrene	.004	Benz-A-Pyrene
Oil %	.43	
Water %	25	
Solids %	74.6	Rust, Corrosion Products Silt from River

* Based on engineering judgment.

TABLE C-15

COOLING TOWER SLUDGE

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	3.5	Phenols
Cyanide	.1	Cyanide
Selenium	.015	Carbonates/Oxides
Arsenic	8.2	Carbonates/Oxides
Mercury	.09	Carbonates/Oxides
Beryllium	.0013	Carbonates or Oxides
Vanadium	7.8	Carbonates or Oxides
Chromium	554	Carbonates or Oxides
Cobalt	1.3	Carbonates or Oxides
Nickel	6.8	Carbonates or Oxides
Copper	50	Carbonates or Oxides
Zinc	675	Carbonates or Oxides
Silver	.28	Carbonates or Oxides
Cadmium	.3	Carbonates or Oxides
Lead	38	Carbonates or Oxides
Molybdenum	1.1	Carbonates or Oxides
Ammonia Salts	6.3	Ammonium Sulfate
Benz-A-Pyrene	.004	Benz-A-Pyrene
Oil %	.44	
Water %	75.4	
Solids %	24.16	Mostly from Wind-Blown Dirt

* Based on engineering judgment.

TABLE C-16

FCC CATALYST FINES

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	2.1	Phenols
Cyanide	.12	Cyanide
Selenium	.01	Oxide or Silicate, Insoluble
Arsenic	1.0	Arsenic
Mercury	.0004	Oxide or Silicate, Insoluble
Beryllium	.5	Oxide or Silicate, Insoluble
Vanadium	240	Oxide or Silicate, Insoluble
Chromium	71	Oxide or Silicate, Insoluble
Cobalt	6.6	Oxide or Silicate, Insoluble
Nickel	241	Oxide or Silicate, Insoluble
Copper	17.5	Oxide or Silicate, Insoluble
Zinc	39	Oxide or Silicate, Insoluble
Silver	1.8	Oxide or Silicate, Insoluble
Cadmium	.003	Oxide or Silicate, Insoluble
Lead	50	Oxide or Silicate, Insoluble
Molybdenum	6.3	Oxide or Silicate, Insoluble
Ammonia Salts	.01	Ammonium Sulfate
Benz-A-Pyrene	.005	Benz-A-Pyrene
Oil %	.21	Essentially Tar
Water %	0	
Solids %	99.79	Refined Sand

* Based on engineering judgment.

TABLE C-17

COKE FINES

Parameters	Concentration (mg/kg)	Form of Occurrence*
Phenols	2.0	Phenols
Cyanide	.001	Cyanide
Selenium	01	
Arsenic	2.0	Arsenic
Mercury	.04	
Beryllium	.005	
Vanadium	455	Carbide
Chromium	.02	
Cobalt	4.0	
Nickel	580	Carbide
Copper	4.0	
Zinc	14	
Silver	.01	
Cadmium	1.0	
Lead	13.0	
Molybdenum	.1	
Ammonia Salts	.7	Ammonium Sulfate
Benz-A-Pyrene	.002	Benz-A-Pyrene
Oil %	.001	
Water %	0	
Solids %	100	Coke (Carbon)

* Based on engineering judgment.

APPENDIX D

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

A discussion of the value of recoverable materials and energy was included in Section 2.6. This section includes a detailed item by item breakdown of the market value for all metals and oil in each of the 17 waste streams. The dollar values represent maximum values for metals since recovered material seldom commands the price of fresh materials. The value of oil is based on \$8/bbl or \$50/cu m.

TABLE D-1

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	SLOP OIL EMULSION SOLIDS			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/kg *
SELENIUM	1.0	0.276	12.69	46.00
ARSENIC	7.4	2.04	0.51	.25
MERCURY	0.59	0.162	1.42	8.8
BERYLLIUM	0.0025	0.00069	0.031	46.00(1
VANADIUM	25.	6.90	53.89	7.81
CHROMIUM	525.	144.90	305.73	2.11
COBALT	10.	2.76	26.71	9.68
NICKEL	50.	13.80	60.72	4.4
COPPER	48.	13.24	20.38	1.54
ZINC	250.	69.00	58.65	.85
SILVER	0.4	0.110	16.87	153.4
CADMIUM	0.19	0.052	0.34	6.6
LEAD	28.1	7.75	3.41	.44
MOLYBDENUM	5.	1.38	9.71	7.04
TOTAL METAL			571.	
OIL			55,200	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-2

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	SILT FROM STORMWATER RUNOFF			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/kg *
SELENIUM	1.7	0.68	31.28	46.00
ARSENIC	5.5	2.2	0.55	.25
MERCURY	0.30	0.12	0.001	8.8
BERYLLIUM	0.0019	0.00076	0.034	46.00(1
VANADIUM	69.	27.6	215.55	7.81
CHROMIUM	354	141.6	298.77	2.11
COBALT	11.2	4.48	43.36	9.68
NICKEL	85.	34.	149.60	4.4
COPPER	28.3	11.32	17.43	1.54
ZINC	230.	92.	78.20	.85
SILVER	0.5	0.2	30.68	153.4
CADMIUM	0.22	0.088	0.58	6.6
LEAD	53.3	21.32	9.38	.44
MOLYBDENUM	6.9	2.76	19.43	7.04
TOTAL METAL			895	
OIL			1100	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-3

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	EXCHANGER BUNDLE CLEANING SLUDGE			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/kg *
SELENIUM	27.2	1.79	82.34	46.00
ARSENIC	10.6	0.699	0.17	.25
MERCURY	1.9	0.125	1.10	8.8
BERYLLIUM	0.20	0.013	0.60	46.00(1
VANADIUM	25.	1.65	12.88	7.81
CHROMIUM	311.	20.52	43.29	2.11
COBALT	1.6	0.105	1.01	9.68
NICKEL	116.	7.65	33.66	4.4
COPPER	71	4.68	7.20	1.54
ZINC	194.	12.80	10.88	.85
SILVER	0.005	0.00033	0.05	153.4
CADMIUM	1.3	0.085	0.56	6.6
LEAD	78.	5.14	2.26	.44
MOLYBDENUM	6.5	0.429	3.02	7.04
TOTAL METAL			199	
OIL			975	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-4

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	API SEPARATOR SLUDGE			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	0.001	.00044	0.02	46.00
ARSENIC	6.2	2.72	0.68	.25
MERCURY	0.4	0.176	1.54	8.8
BERYLLIUM	0.0025	0.0011	0.05	46.00 (1
VANADIUM	9.8	4.31	33.66	7.81
CHROMIUM	253.	111.32	234.88	2.11
COBALT	5.7	2.50	24.20	9.68
NICKEL	19.3	8.49	37.35	4.4
COPPER	18.6	8.18	12.59	1.54
ZINC	298.	131.	111.35	.85
SILVER	0.45	0.198	30.37	153.4
CADMIUM	0.42	0.184	1.21	6.6
LEAD	26.	11.44	5.03	.44
MOLYBDENUM	5.	2.2	15.48	7.04
TOTAL METAL			508	
OIL			20,400	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-5

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	NON-LEADED PRODUCT TANK BOTTOMS			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	12.	11.04	507.84	46.00
ARSENIC	0.007	0.0064	0.0016	.25
MERCURY	0.43	0.395	3.47	8.8
BERYLLIUM	0.26	0.239	10.99	46.00(1
VANADIUM	21.9	20.14	157.29	7.81
CHROMIUM	12.9	11.86	25.02	2.11
COBALT	7.1	6.53	63.21	9.68
NICKEL	26.7	24.56	108.06	4.4
COPPER	85.1	78.29	120.56	1.54
ZINC	285.	262.2	222.87	.85
SILVER	0.6	0.55	84.37	153.4
CADMIUM	0.33	0.303	2.00	6.6
LEAD	24.7	22.72	9.99	.44
MOLYBDENUM	9.2	8.46	59.55	7.04
TOTAL METAL			1379.	
OIL ••			163,200	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-6

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	CRUDE TANK BOTTOMS			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	0.03	0.00033	0.015	46.00
ARSENIC	21.1	0.238	0.059	.25
MERCURY	0.48	0.0054	0.047	8.8
BERYLLIUM	0.0026	0.000025	0.0011	46.00(1)
VANADIUM	17.4	0.196	1.53	7.81
CHROMIUM	19.4	0.219	0.46	2.11
COBALT	14.8	0.167	1.61	9.68
NICKEL	16.2	0.183	0.80	4.4
COPPER	65.4	0.739	1.13	1.54
ZINC	145.	1.63	1.38	.85
SILVER	0.19	0.0021	0.32	153.4
CADMIUM	0.31	0.0035	0.02	6.6
LEAD	18.9	0.213	0.09	.44
MOLYBDENUM	6.3	0.071	0.50	7.04
TOTAL METAL			8	
OIL			680	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-7

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	LEADED TANK BOTTOMS			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/kg *
SELENIUM	6.95	0.160	7.36	46.00
ARSENIC	294.	6.79	1.69	.25
MERCURY	0.57	0.013	0.11	8.8
BERYLLIUM	0.0025	0.00005	0.0023	46.00(1
VANADIUM	5.4	0.124	0.96	7.81
CHROMIUM	11.4	0.263	0.55	2.11
COBALT	49.	1.13	10.93	9.68
NICKEL	314	7.25	31.90	4.4
COPPER	141	3.25	5.00	1.54
ZINC	9090.	209.97	178.47	.85
SILVER	0.88	0.020	3.06	153.4
CADMIUM	6.3	0.145	0.95	6.6
LEAD	790.	18.25	8.03	.44
MOLYBDENUM	59.	1.36	9.57	7.04
TOTAL METAL			258	
OIL			290	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-8

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	DISSOLVED AIR FLOTATION UNIT			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	2.0	1.46	67.16	46.00
ARSENIC	2.0	1.46	.06	.25
MERCURY	.27	.197	1.73	8.8
BERYLLIUM	0.0025	0.0018	0.08	46.00(1
VANADIUM	0.05	0.036	0.28	7.81
CHROMIUM	140.	102.2	215.64	2.11
COBALT	2.0	1.46	14.13	9.68
NICKEL	0.025	0.018	0.08	4.4
COPPER	7.0	5.11	7.86	1.54
ZINC	85.	62.05	57.74	.85
SILVER	0.25	0.182	27.91	153.4
CADMIUM	0.005	0.0036	0.23	6.6
LEAD	7.5	5.47	2.40	.44
MOLYBDENUM	0.05	0.036	0.25	7.04
TOTAL METAL			395	
OIL			82,500	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-9

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	KEROSENE FILTER CLAYS			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/kg *
SELENIUM	9.6	1.78	81.88	46.00
ARSENIC	2.2	0.409	0.10	.25
MERCURY	0.0004	0.000074	0.0006	8.8
BERYLLIUM	0.2	0.037	1.70	46.00(1
VANADIUM	35.	6.51	50.34	7.81
CHROMIUM	2.88	0.535	1.12	2.11
COBALT	0.62	0.115	1.11	9.68
NICKEL	0.04	0.007	0.03	4.4
COPPER	11.4	2.12	3.26	1.54
ZINC	25.	4.65	3.95	.85
SILVER	0.5	0.093	14.26	153.4
CADMIUM	0.25	0.046	0.30	6.6
LEAD	8.3	1.54	0.67	.44
MOLYBDENUM	0.025	0.0046	0.03	7.04
TOTAL METAL			159	
OIL			350	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-10

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	LUBE OIL FILTER CLAYS			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	1.1	2.12	97.52	46.00
ARSENIC	0.7	1.35	0.33	.25
MERCURY	0.19	0.366	3.22	8.8
BERYLLIUM	0.26	0.501	23.04	46.00(1
VANADIUM	33.	63.59	496.63	7.81
CHROMIUM	23.2	44.70	94.31	2.11
COBALT	3.2	6.16	59.04	9.68
NICKEL	11.1	21.39	94.11	4.4
COPPER	4.3	8.28	12.75	1.54
ZINC	57.8	111.38	94.67	.85
SILVER	0.5	0.96	147.26	153.4
CADMIUM	0.76	1.46	9.63	6.6
LEAD	1.28	2.46	1.08	.44
MOLYBDENUM	0.038	0.073	0.51	7.04
TOTAL METAL			1134.	
OIL			28,850	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-11

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	NEUTRALIZED HF ALKYLATION SLUDGE			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	7.1	2.27	104.42	46.00
ARSENIC	2.3	0.736	0.18	.25
MERCURY	0.07	0.022	0.19	8.8
BERYLLIUM	0.07	0.022	1.01	46.00(1
VANADIUM	2.6	0.832	6.49	7.81
CHROMIUM	2.8	0.896	1.89	2.11
COBALT	0.36	0.115	1.11	9.68
NICKEL	55.2	17.66	77.70	4.4
COPPER	14.3	4.57	7.03	1.54
ZINC	9.1	2.91	2.47	.85
SILVER	0.19	0.06	9.20	153.4
CADMIUM	0.07	0.022	0.14	6.6
LEAD	7.1	2.27	0.99	.44
MOLYBDENUM	0.0025	0.0008	0.005	7.04
TOTAL METAL			217	
OIL			2850	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-12

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	SPENT LIME FROM BOILER FEEDWATER TREATMENT			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	0.01	0.057	2.62	46.00
ARSENIC	0.1	0.577	0.14	.25
MERCURY	0.04	0.231	2.03	8.8
BERYLLIUM	0.0012	0.0069	0.31	46.00(1
VANADIUM	0.05	0.288	2.24	7.81
CHROMIUM	2.2	12.70	26.79	2.11
COBALT	0.005	0.0288	0.27	9.68
NICKEL	2.5	14.43	63.49	4.4
COPPER	3.8	21.94	33.78	1.54
ZINC	15.0	86.62	73.62	.85
SILVER	0.5	2.88	441.79	153.4
CADMIUM	0.003	0.0173	0.11	6.6
LEAD	3.8	21.94	9.65	.44
MOLYBDENUM	0.025	0.144	1.01	7.04
TOTAL METAL			658	
OIL			2250	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-13

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	WASTE BIO SLUDGE			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/kg *
SELENIUM	0.01	0.0016	0.07	46.00
ARSENIC	3.8	0.608	0.15	.25
MERCURY	0.18	0.028	0.24	8.8
BERYLLIUM	0.0013	0.002	0.0092	46.00(1
VANADIUM	0.05	0.008	0.06	7.81
CHROMIUM	300	48.	101.28	2.11
COBALT	0.02	0.0032	0.03	9.68
NICKEL	0.025	0.004	0.01	4.4
COPPER	9.5	1.52	2.34	1.54
ZINC	122.	19.52	16.59	.85
SILVER	0.3	0.048	7.36	153.4
CADMIUM	0.3	0.048	0.31	6.6
LEAD	5.0	0.8	0.35	.44
MOLYBDENUM	2.5	0.4	2.81	7.04
TOTAL METAL			132	
OIL			175	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-14

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	ONCE THRU COOLING WATER SLUDGE			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	1.6	4.03	135.38	46.00
ARSENIC	5.4	13.6	3.40	.25
MERCURY	0.51	1.28	11.28	8.8
BERYLLIUM	0.24	0.60	27.60	46.00(1)
VANADIUM	39	98.28	767.56	7.81
CHROMIUM	63	158.7	334.85	2.11
COBALT	6.3	15.87	153.62	9.68
NICKEL	35.	88.2	388.08	4.4
COPPER	153.	385.5	592.90	1.54
ZINC	125.	315.	267.75	.85
SILVER	0.5	1.26	192.28	153.4
CADMIUM	0.003	0.007	0.04	6.6
LEAD	57.	143.6	63.18	.44
MOLYBDENUM	2.5	6.3	44.35	7.04
TOTAL METAL			3032	
OIL			725	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-15

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	COOLING TOWER SLUDGE			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/kg *
SELENIUM	0.015	0.000087	0.04	46.00
ARSENIC	8.2	0.047	0.01	.25
MERCURY	0.09	0.00052	0.004	8.8
BERYLLIUM	0.0013	0.0000075	0.00034	46.00(1
VANADIUM	7.8	0.045	0.35	7.81
CHROMIUM	554.	3.21	6.77	2.11
COBALT	1.3	0.0075	0.07	9.68
NICKEL	6.8	0.036	0.15	4.4
COPPER	50.	0.29	0.44	1.54
ZINC	675.	3.91	3.32	.85
SILVER	0.28	0.0016	0.24	153.4
CADMIUM	0.3	0.0017	0.01	6.6
LEAD	38.	0.22	0.096	.44
MOLYBDENUM	1.1	0.0063	0.04	7.04
TOTAL METAL			12	
OIL			0	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-16

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	FLUID CATALYTIC CRACKER CATALYST FINES			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	0.01	0.0037	0.17	46.00
ARSENIC	1.0	0.3702	0.09	.25
MERCURY	0.0004	0.00014	0.001	8.8
BERYLLIUM	0.5	0.185	8.50	46.00(1
VANADIUM	240.	88.84	693.84	7.81
CHROMIUM	71.	26.28	55.45	2.11
COBALT	6.6	2.44	23.61	9.68
NICKEL	241	89.21	392.52	4.4
COPPER	17.5	6.47	9.96	1.54
ZINC	39.	14.43	12.26	.85
SILVER	1.8	0.666	102.16	153.4
CADMIUM	0.003	0.001	0.04	6.6
LEAD	50.	18.51	8.14	.44
MOLYBDENUM	6.3	2.33	16.40	7.04
TOTAL METAL			1323	
OIL			40	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

TABLE D-17

POTENTIAL MARKET VALUE OF MATERIALS AND ENERGY

PARAMETERS	COKE FINES			
	Concentration mg/kg	Total Quantity kg/yr	Dollars Per Year	Dollars/ kg *
SELENIUM	0.01	0.0000016	0.0000009	46.00
ARSENIC	2.0	0.0032	0.008	.25
MERCURY	0.04	0.000064	0.00056	8.8
BERYLLIUM	0.005	0.000008	0.000037	46.00(1
VANADIUM	455.	0.728	5.68	7.81
CHROMIUM	0.02	0.000032	0.000067	2.11
COBALT	4.0	0.0064	0.06	9.68
NICKEL	580.	0.928	4.08	4.4
COPPER	4.0	0.0064	0.009	1.54
ZINC	14.	0.0224	0.02	.85
SILVER	0.01	0.000016	0.0024	153.4
CADMIUM	1.0	0.0016	0.01	6.6
LEAD	13.0	0.0208	0.009	.44
MOLYBDENUM	0.1	0.0016	0.001	7.04
TOTAL METAL			9	
OIL			0	

(1) No price available; assumed same as Selenium

* October 1976 prices from Chemical Marketing Reporter

APPENDIX E

DESIGN OF PHASE SEPARATION SYSTEM

This section develops detailed specifications for each unit of the phase separation system. Discussion of the process and process schematics is included in Section 4. These specifications were supplied to vendors for price quotations which are the basis for our cost estimates.

This section also includes typical properties for various solvents discussed in Section 4.1.

Note

It is not meaningful to write the enclosed specs in Metric System since the equipment is manufactured in the FPS System.

2/28/77
By KJ

A-1

EPA
27-1656

SLUDGE/ACETONE MIXER

Feeds to Mixer

	1 lb/hr	2 lb/hr
Oil	1782	
H_2O	3528	170
Acetone		16,825
Solids	1250	
	6,560	16,995

Specify a 2" Kenics type mixer containing two elements. (Each element contains 6 helix pieces.)

JACOBS ENGINEERING CO.

PAGE_______ OF_______ PAGES

AGITATOR DATA SHEET

NOTE: VENDOR TO COMPLETE ALL INFORMATION

PROJECT NO 27-1656 ITEM NO A-2, A-3

SPECIFICATION NO

DATE 3/1/77 REVISION

FOR EPA

SERVICE Slurry Agitator

SITE

MFR

NO REQD 2 ☐ PORTABLE ☐ SIDE-ENTERING ☐ TOP ENTERING ☐ OTHER

SIZE AND MODEL

CONDITIONS

KIND OF PROCESS			
☐ ALL LIQUIDS	☒ LIQUID-SOLID	☐ LIQUID-GAS	TEMP OPER Amb. DESIGN
☐ BLENDING MISCIBLE LIQUIDS	☐ SUSPEND SOLIDS UNIFORMLY	☐ GAS ABSORPTION	PRESS OPER Amb. DESIGN
☐ CONTACTING IMMIS LIQUIDS	☒ SUSPEND SOLIDS ENTIRELY OFF BOTTOM	☐ GAS DISPERSION	MIXTURE S G VISC
☐ CHEMICAL REACTION		☐ GAS STRIPPING	MIXING CYCLE ☐ BATCH ☒ CONT (1)
☐ POLYMERIZATION	☐ SUSPEND SOLIDS ADEQUATELY TO PREVENT BUILD-UP	☐	BATCH NORMAL GALLONS 7265
☐ HEAT TRANSFER			RANGE GALLONS
☐ PUMPING	☐ DISSOLVING		CONTINUOUS FLOW RATE GPM 15
☐	☐ WASHING OR LEACHING		DUTY ☐ INTERMITTENT HRS D
☐	☐		☐ CONTINUOUS

LIQUID NO 1	SOLID	GAS	VESSEL DESIGN
NAME Oil	NAME Sludge	NAME	DIMENSIONS
WT % 27 SG 0.85	WT % 19 SG 2.40	FLOW RATE SCFM	
VISC SHEAR RATE	SETTLING VELOCITY FPM	MOL WT	TOP ☐ CLOSED ☒ OPEN
	SHAPE some spheres	TEMP	CLOSED TOP ☐ FLAT ☐ DISHED ☐ ASME
	some flakes	PRESS	BOTTOM ☐ FLAT ☐ DISHED ☐ ASME
			☒ CONE DEPTH 2'
	SIEVE ANALYSIS:		BAFFLES NO 0 SIZE
	Not available		STEADY BEARING ☐ PERMISSIBLE ☐ NOT PERMISSIBLE
LIQUID NO 2			MOUNTING NOZZLE SIZE
NAME			LARGEST OPENING TO INSERT IMPELLER
WT % 54 SG 1.00			HEAD ROOM LIMITATION
VISC SHEAR RATE	☐ ABRASIVE	☐ FOAMS	
	☐ HARD TO WET		
	☐ STICKY		

DESIGN	MATERIALS OF CONSTRUCTION
IMPELLER DIA 36" NO 1 TYPE RPM 80	IMPELLER
SEAL ☐ PACKING ☐ SINGLE MECH ☐ DOUBLE MECH ☐ OTHER	SHAFT
LENGTH OF GEAR/DRIVER UNIT FR MOUNTING FLANGE	STEADY BEARING
COUPLING COUPLING GUARD	SEAL LUBRICANT
DRIVER TYPE	

MOTOR DRIVER	SPEED REDUCER	WEIGHTS
HP 20 RPM FRAME	MAKE	DRIVER UNIT
MFR	TYPE	SHAFT & IMPELLER
TYPE INSUL	CLASS	TOTAL UNIT
ENC TEMP RISE C	SPEED RATIO	
VOLTS PHASE/CYCLES	SERVICE FACTOR	
BEARINGS LUBE		

(1) Two tanks operating - one is filled to 7265 gallons and agitated until the other is empty. It is then put on line and slurry is drawn out at a rate of 15 gpm.

JACOBS ENGINEERING CO. **VESSEL SPECIFICATION**

CUSTOMER EPA		PROJECT 27-1656	ITEM C-1
LOCATION		DATE 3-1-77	JOB 27-1656
SERVICE Acetone Absorber		BY KJ	PAGES PAGE
NO	SIZE	LENGTH	CODE SPECIFICATION
PSW 25 PSIG	TSW 300 F	CORROSION 1/8"	SR XR

PART	MATERIAL	DESCRIPTION
SHELL		
HEADS		SEMIELLIP—DISHED
SUPPORTS		SKIRT—SADDLES—LEGS
MANHOLES		HINGE—DAVIT
NOZZLES		
COUPLINGS		
INTERNALS		
CLIPS		LADDER—PLATFORM
RINGS		INSULATION—VACUUM
PAINT		
DAVIT		

(See attached drawing)

NOZZLES

	SERVICE	NO	SIZE	RATING	FACING
N1	Water Feed				
N2	Scrubbed Vapor Out				
N3	Vent Gas In				
N4	Nitrogen Out				
N5	Product Soln. Out				
N6	Gas In				
N7	Water In				
N8	Water Out				

REMARKS

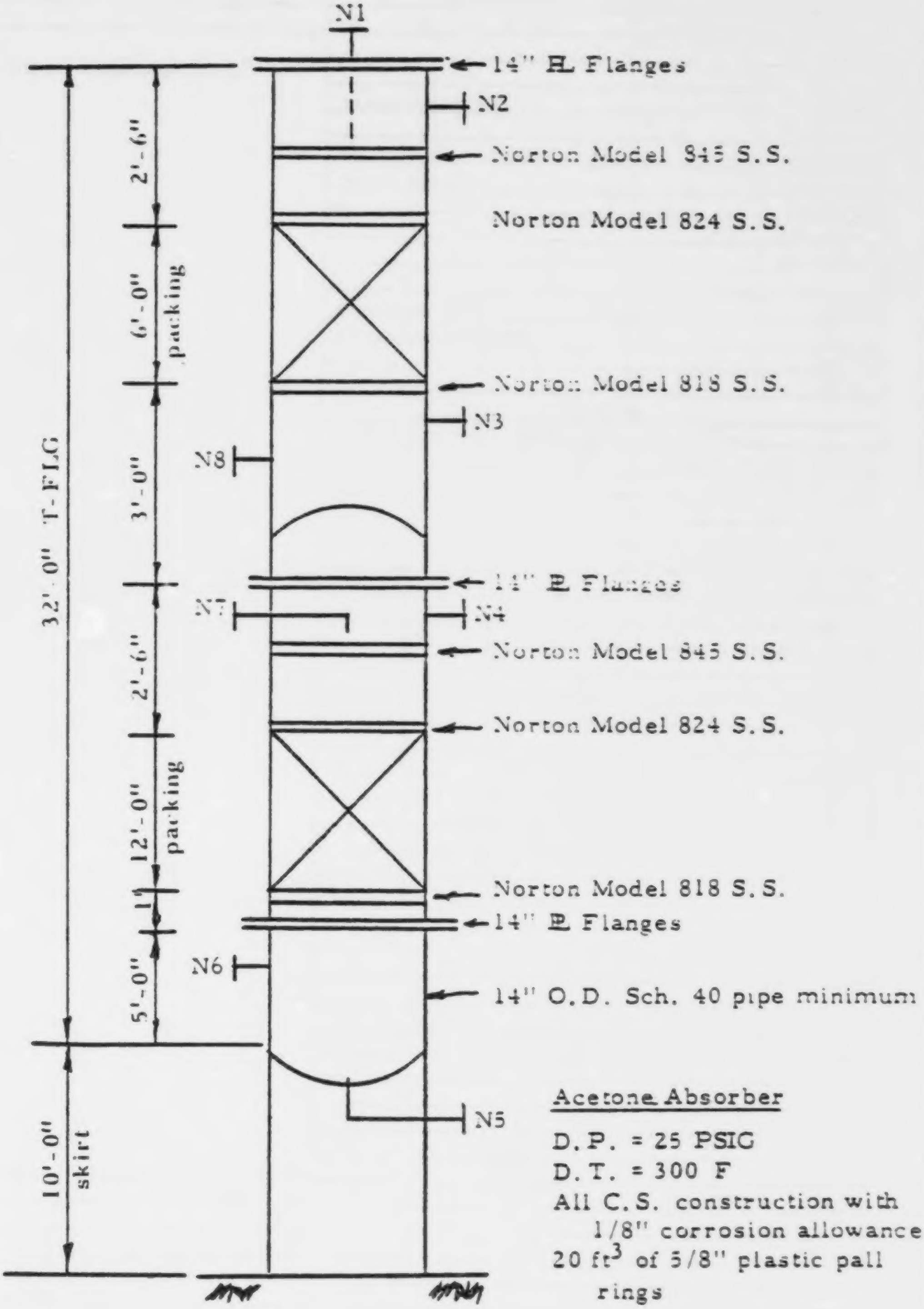
NO	DATE	REVISION

FORM 1361

3/1/77
By KJ

ACETONE ABSORBER

EPA
27-1656


N1
14" PL Flanges
N2
Norton Model 845 S.S.
Norton Model 824 S.S.
Norton Model 818 S.S.
N3
N8
14" PL Flanges
N7
N4
Norton Model 845 S.S.
Norton Model 824 S.S.
Norton Model 818 S.S.
14" PL Flanges
N6
14" O.D. Sch. 40 pipe minimum
N5
2'-6"
6'-0" packing
3'-0"
2'-6"
12'-0" packing
1'
5'-0"
32'-0" T-FLG
10'-0" skirt

Acetone Absorber

D.P. = 25 PSIG
D.T. = 300 F
All C.S. construction with
1/8" corrosion allowance
20 ft^3 of 5/8" plastic pall
rings

Reproduced from
best available copy.

JACOBS ENGINEERING CO. **VESSEL SPECIFICATION**

CUSTOMER EPA
PROJECT 27-1656 ITEM C-2
LOCATION
DATE 3-1-77 JOB 27-1656
SERVICE Acetone Distillation Column
BY KJ PAGES PAGE

NO SIZE LENGTH CODE SPECIFICATION
PSW 25 PSIG TSW 300 F CORROSION 1/8" SR XR

PART	MATERIAL	DESCRIPTION
SHELL		
HEADS		SEMIELLIP—DISHED
SUPPORTS		SKIRT—SADDLES—LEGS
MANHOLES		HINGE—DAVIT
NOZZLES		
COUPLINGS		
INTERNALS		
CLIPS		LADDER—PLATFORM
RINGS		INSULATION—VACUUM
PAINT		
DAVIT		

(See attached drawing)

NOZZLES

	SERVICE	NO	SIZE	RATING	FACING
N1	Vapor Out				
N2	Reflux In				
N3	Feed In				
N4	Feed In				
N5	Reboiler Return				
N6	Reboiler Feed				

REMARKS

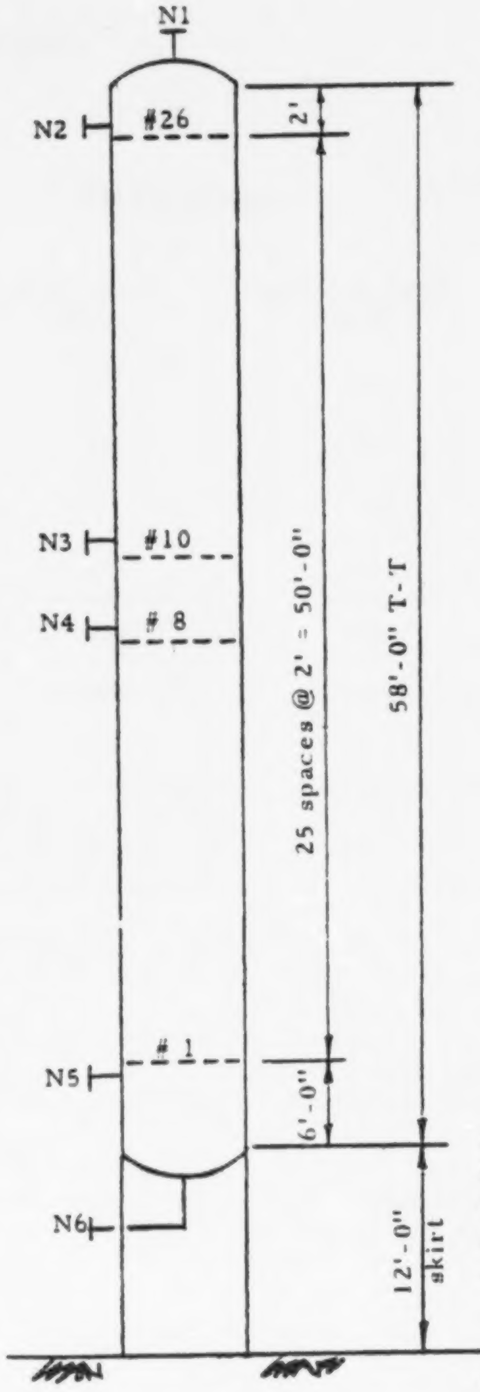
NO	DATE	REVISION

FORM 1321

3/1/77
By KJ

EPA
27-1656

ACETONE RECOVERY COLUMN


N1
N2
#26
2'
N3
#10
N4
# 8
25 spaces @ 2' = 50'-0"
58'-0" T-T
# 1
N5
6'-0"
N6
12'-0"
skirt

D.P. = 25 PSIG
D.T. = 300 F
C.A. = 1/8"
All C.S. Construction

Trays: Type 410 S.S.
14 gauge
sieve trays
Column is 48" I.D.

2/29/77
By KJ

D-1

EPA
27-1656

SOLIDS DRIER

	Feed to Drier	Drier Product, Solids		Vapor Product
	lb/hr	lb/hr	wt %	lb/hr
Oil	30	30	2.28	
H_2O	62	36	2.74	26
Acetone	283	0.1	0.01	282.9
Solids	1250	1250	94.97	
	1625	1316.1	100.00	308.9
T F	100 F	300 F		250 F

Specify a "Porcupine" unit by Bethlehem Corp.
225 W. Second St.
Bethlehem, PA 18016
(215) 258-7111

Heat necessary for the vaporization of absorbed liquids is to be supplied by 150# steam fed directly into the Porcupine unit. As the vapors are formed, they are removed from the drier with a carrier gast stream of composition given below. The carrier gas enters the drier at 200 F and the total vapor stream leaves at 250 F. The solids leave at 300 F. The steam required to provide the necessary duty has been estimated to be 186 lb/hr.

	Circulating Gas
	lb/hr
N_2	420
H_2O	14
Acetone	10
	444

Project 27-1656

SERVICE Dryer Effluent - Nitrogen Exchanger ITEM E-1

TYPE S & T

TUBE-SURFACE, BASED ON OD AND OVERALL LENGTH

PERFORMANCE	INSHELL	INTUBES
FLUID	Acetone, H_2O, N_2 (1)	Acetone, H_2O, N_2 (2)
TOTAL INFLUENT, LB. PER HR.	752.9	444
LIQUID		
VAPOR	752.9	430
NONCONDENSABLES	712.9	430
STEAM	40	14
FLUID CONDENSED OR VAPORIZED, LB. PER HR.		
GRAVITY, LIQUID AT 60 F.		
VISCOSITY, CENTIPOISES	AT F	AT F
MOLECULAR WEIGHT VAPOR	33.82	27.90
SPECIFIC HEAT, BTU PER LB. PER DEG F.	0.310 AT 225 F	0.260 AT 150 F
LATENT HEAT, BTU PER LB.	AT F	AT F
TEMPERATURE IN, F.	250	100
TEMPERATURES OUT, F.	201	200
PRESSURE, PSIG AT INLET	2	5
VELOCITY, FPS.		
PRESSURE DROP, PSI CLEAN EXCHANGER	1	1.5
HEAT EXCHANGED, BTU PER HR. 11,420	LOG MTD. F.	CORRECTED MTD. F.
HEAT-TRANSFER RATE REQUIRED, BTU PER HR. PER SQ. FT. PER F.		FOULING FACTOR 0.004 total
DESIGN	INSHELL	INTUBES
PRESSURE, PSIG	25	25
HYDROSTATIC TEST, PSIG		
TEMPERATURE, F.	300	250
CORROSION-ALLOWANCE, INCH	1/8"	1/8"
PIPING-CONNECTIONS, IN-OUT		
NOZZLE-ARRANGEMENT		
PASSES		
TUBE-LAYOUT	INCH PITCH	

MATERIALS

TUBES C.S. INCH OD GAGE INCHES LONG

TUBESHEETS C.S.

CHANNEL C.S.

SHELL C.S.

WEIGHTS, POUNDS EACH EXCHANGER, EMPTY FULL OF WATER TUBEBUNDLE

GENERAL

STRESS RELIEVED PARTS ARE MARKED SR RADIOGRAPHED PARTS XR

CONSTRUCTION ACCORDS WITH ASME VIII; TEMA R

REMARKS: (1) Composition, wt %: Acetone = 38.90%, H_2O = 5.31, N_2 = 55.79

(2) Composition, wt %: Acetone = 2.25%, H_2O = 3.15, N_2 = 94.60

JACOBS ENGINEERING CO. **HEAT EXCHANGER SPECIFICATION**

			Project 27-1656
SERVICE Absorber Feed Cooler			ITEM E-2
TYPE			
TUBE-SURFACE, BASED ON OD AND OVERALL LENGTH			
PERFORMANCE	INSHELL		INTUBES
FLUID	Acetone, H_2O, N_2 (1)		Cooling H_2O
TOTAL INFLUENT, LB. PER HR.	752.9		4,200
LIQUID			4,200
VAPOR	752.9		
NONCONDENSABLES	712.9		
STEAM	40		
FLUID CONDENSED OR VAPORIZED, LB. PER HR.	21.3 (2)		
GRAVITY, LIQUID AT 60 F.			
VISCOSITY, CENTIPOISES	AT F		AT F
MOLECULAR WEIGHT VAPOR In/Out	33.82/34.50		
SPECIFIC HEAT, BTU PER LB. PER DEG F.	0.55 AT 150 F		AT F
LATENT HEAT, BTU PER LB.	AT F		AT F
TEMPERATURE IN, F.	201		90
TEMPERATURES OUT, F.	100		100
PRESSURE, PSIG AT INLET	1		50
VELOCITY, FPS.			
PRESSURE DROP, PSI CLEAN EXCHANGER	1		5
HEAT EXCHANGED, BTU PER HR. 42,000	LOG MTD. F.		CORRECTED MTD. F.
HEAT-TRANSFER RATE REQUIRED, BTU PER HR. PER SQ. FT. PER F.			FOULING FACTOR 0.004 total
DESIGN	INSHELL		INTUBES
PRESSURE; PSIG	25		75
HYDROSTATIC TEST, PSIG			
TEMPERATURE, F.	250		150
CORROSION-ALLOWANCE, INCH	1/8"		1/8"
PIPING-CONNECTIONS, IN-OUT			
NOZZLE-ARRANGEMENT			
PASSES			
TUBE-LAYOUT	INCH PITCH		
MATERIALS			
TUBES C.S.	INCH OD	GAGE	INCHES LONG
TUBESHEETS C.S.			
CHANNEL C.S.			
SHELL C.S.			
WEIGHTS, POUNDS EACH EXCHANGER, EMPTY	FULL OF WATER		TUBEBUNDLE
GENERAL			
STRESS RELIEVED PARTS ARE MARKED SR RADIOGRAPHED PARTS XR			
CONSTRUCTION ACCORDS WITH ASME VIII: TEMA R			

REMARKS:

(1) Composition wt%: Acetone = 38.90%, H_2O = 5.31%, N_2 = 55.79

(2) Composition (liq) wt%: Acetone = 15.49%, H_2O = 84.51%

JACOBS ENGINEERING CO. **HEAT EXCHANGER SPECIFICATION**

Project 27-1656

SERVICE Acetone Feed Cooler		ITEM E-3
TYPE		
TUBE-SURFACE, BASED ON OD AND OVERALL LENGTH		
PERFORMANCE	INSHELL	INTUBES
FLUID	Acetone, H_2O (1)	Cooling H_2O
TOTAL INFLUENT, LB. PER HR.	16,995	29,900
LIQUID	16,995	29,900
VAPOR		
NONCONDENSABLES		
STEAM		
FLUID CONDENSED OR VAPORIZED, LB. PER HR.		
GRAVITY, LIQUID AT 60 F.		
VISCOSITY, CENTIPOISES	AT F	AT F
MOLECULAR WEIGHT VAPOR	56.81	
SPECIFIC HEAT, BTU PER LB. PER DEG F.	0.55 AT 116 F	AT F
LATENT HEAT, BTU PER LB.	AT F	AT F
TEMPERATURE IN, F.	132	90
TEMPERATURES OUT, F.	100	100
PRESSURE, PSIG AT INLET	40	50
VELOCITY, FPS.		
PRESSURE DROP, PSI CLEAN EXCHANGER	5	5
HEAT EXCHANGED, BTU PER HR. 299,000	LOG MTD. F.	CORRECTED MTD. F.
HEAT-TRANSFER RATE REQUIRED, BTU PER HR. PER SQ. FT. PER F.		FOULING FACTOR 0.004 total
DESIGN	INSHELL	INTUBES
PRESSURE, PSIG	75	75
HYDROSTATIC TEST, PSIG		
TEMPERATURE, F.	250	150
CORROSION-ALLOWANCE, INCH	1/8"	1/8"
PIPING-CONNECTIONS, IN-OUT		
NOZZLE-ARRANGEMENT		
PASSES		
TUBE-LAYOUT	INCH PITCH	
MATERIALS		
TUBES	INCH OD	GAGE INCHES LONG
TUBESHEETS		
CHANNEL		
SHELL		
WEIGHTS, POUNDS EACH EXCHANGER, EMPTY	FULL OF WATER	TUBEBUNDLE
GENERAL		
STRESS RELIEVED PARTS ARE MARKED SR RADIOGRAPHED PARTS XR		
CONSTRUCTION ACCORDS WITH ASME VIII: TEMA R		

REMARKS: (1) Composition wt %: Acetone = 99.0%, H_2O = 1.0%

JACOBS ENGINEERING CO. **HEAT EXCHANGER SPECIFICATION**

Project 27-1656

SERVICE Distillation Condenser		ITEM E-4
TYPE S & T		
TUBE-SURFACE, BASED ON OD AND OVERALL LENGTH		
PERFORMANCE	INSHELL	INTUBES
FLUID	Steam, Acetone	Cooling H_2O
TOTAL INFLUENT, LB. PER HR.	31,317	367,400
LIQUID		367,400
VAPOR		
~~NONCONDENSABLES~~ Acetone Vapor	31,004	
STEAM		
FLUID CONDENSED OR VAPORIZED, LB. PER HR.	31,317	
GRAVITY, LIQUID AT 60 F.		
VISCOSITY, CENTIPOISES	AT F	AT F
MOLECULAR WEIGHT VAPOR	56.02	
SPECIFIC HEAT, BTU PER LB. PER DEG F.	AT F	AT F
LATENT HEAT, BTU PER LB.	AT F	AT F
TEMPERATURE IN, F.	132	90
TEMPERATURES OUT, F.	132	110
PRESSURE, PSIG AT INLET	3	50
VELOCITY, FPS.		
PRESSURE DROP, PSI CLEAN EXCHANGER	2	5
HEAT EXCHANGED, BTU PER HR. 7,348,000	LOG MTD. F.	CORRECTED MTD. F.
HEAT-TRANSFER RATE REQUIRED, BTU PER HR. PER SQ. FT. PER F.		FOULING FACTOR 0.003 total
DESIGN	INSHELL	INTUBES
PRESSURE, PSIG	25	75
HYDROSTATIC TEST, PSIG	250	150
TEMPERATURE, F.	1/8"	1/8"
CORROSION-ALLOWANCE, INCH		
PIPING-CONNECTIONS, IN-OUT		
NOZZLE-ARRANGEMENT		
PASSES		
TUBE-LAYOUT	INCH PITCH	
MATERIALS		
TUBES C.S.	INCH OD	GAGE INCHES LONG
TUBESHEETS C.S.		
CHANNEL C.S.		
SHELL C.S.		
WEIGHTS, POUNDS EACH EXCHANGER, EMPTY	FULL OF WATER	TUBEBUNDLE
GENERAL		
STRESS RELIEVED PARTS ARE MARKED SR RADIOGRAPHED PARTS XR		
CONSTRUCTION ACCORDS WITH ASME VIII; TEMA R		
REMARKS:		

JACOBS ENGINEERING CO. **HEAT EXCHANGER SPECIFICATION**

Project 27-1656

SERVICE Distillation Reboiler		ITEM E-5
TYPE Kettle U-Tube		
TUBE-SURFACE, BASED ON OD AND OVERALL LENGTH		
PERFORMANCE	**INSHELL**	**INTUBES**
FLUID	Water, Oil	Steam
TOTAL INFLUENT, LB. PER HR.	16,277.5	9,806
LIQUID	16,277.5	
VAPOR		9,806
NONCONDENSABLES		
STEAM		9,806
FLUID CONDENSED OR VAPORIZED, LB. PER HR.	8,504.5 vap (steam)	cond. 9,806
GRAVITY, LIQUID AT 60 F.		
VISCOSITY, CENTIPOISES	AT F	AT F
MOLECULAR WEIGHT VAPOR		
SPECIFIC HEAT, BTU PER LB. PER DEG F.	AT F	AT F
LATENT HEAT, BTU PER LB.	AT F	856.85 AT F
TEMPERATURE IN, F.	227.8	366
TEMPERATURES OUT, F.	228	366
PRESSURE, PSIG AT INLET	5	150
VELOCITY, FPS.		
PRESSURE DROP, PSI CLEAN EXCHANGER	negl.	5
HEAT EXCHANGED, BTU PER HR. 8,402,000	LOG MTD. F.	CORRECTED MTD. F.
HEAT-TRANSFER RATE REQUIRED, BTU PER HR. PER SQ. FT. PER F.		FOULING FACTOR 0.010 total
DESIGN	**INSHELL**	**INTUBES**
PRESSURE, PSIG	30	175
HYDROSTATIC TEST, PSIG		
TEMPERATURE, F.	300	450
CORROSION-ALLOWANCE, INCH	1/8"	1/8"
PIPING-CONNECTIONS, IN-OUT		
NOZZLE-ARRANGEMENT		
PASSES		
TUBE-LAYOUT	INCH PITCH	
MATERIALS		
TUBES C.S.	INCH OD	GAGE INCHES LONG
TUBESHEETS C.S.		
CHANNEL C.S.		
SHELL C.S.		
WEIGHTS, POUNDS EACH EXCHANGER, EMPTY	FULL OF WATER	TUBEBUNDLE
GENERAL		
STRESS RELIEVED PARTS ARE MARKED SR RADIOGRAPHED PARTS XR		
CONSTRUCTION ACCORDS WITH ASME VIII: TEMA R		
REMARKS:		

2/27/77
By KJ

F-1

EPA
27-1656

CENTRIFUGE SPECIFICATION

Centrifuge Feed (Continuous)

	lb/hr	lb/ft^3
Oil	1782	53.0
H_2O	3698	62.4
Acetone	16825	48.1
Solids	1250	150.0
	23,555	

Viscosity of Mixture = 0.7 centipoise

Centrifuge solids product not to exceed the following:

	lbs/hr
Oil	30
H_2O	62
Acetone	283
Solids	1250
	1625

= 30% of the weight of the dry solids absorbed liquid remaining (maximum)

Centrifuge is to be of vapor tight continuous type.

JACOBS ENGINEERING CO.

FANS AND BLOWERS

Project No 27-1656

SERVICE Circulating Gas Blower

ITEM NO. K-1

OPERATING CONDITIONS:	
Gas Handled	Comp. Vol. %: N_2 = 94.18%, H_2O = 4.24%, Acetone= 1.08%
Barometer, PSIA	14.7
Weight Flow, lb./min.	7.4
Std. cu. ft./min. (14.7 PSIA, 60F - Dry)	100.6
Inlet Pressure, PSIA	14.7
Inlet Temperature, °F.	100
Relative Humidity, (%)	100
Molecular Weight	27.90
Inlet Volume, CFM	108.3
Discharge Pressure	19.7 PSIA
Operating Horsepower	
DESIGN:	
Manufacturer	
Model	
Type	
Speed RPM	
Outlet Velocity	
Rotation (viewed from shaft end)	
Casing Material	C.S.
Impeller Material	C.S.
Shaft Material	C.S.
Inlet Nozzle Size	
Discharge Nozzle Size	
Discharge Position (observed from shaft end)	
DRIVE:	
Type (direct, v-belt, etc.)	
Guard	
DRIVER BY:	Vendor
Type	
Manufacturer	
Mounted By	
Horsepower	
RPM	
Enclosure	
Volts/Phase/Cycles	120V - 1 PH - 60 CY

ACCESSORY EQUIPMENT:

Base Plate, CPLG

JACOBS ENGINEERING CO.

Project No

FANS AND BLOWERS

27-1656

SERVICE Circulating Gas Blower

ITEM NO. K-1

OPERATING CONDITIONS:

Gas Handled Comp. Vol. %: N_2 = 94.18%, H_2O = 4.24%, Acetone = 1.08%

Barometer, PSIA 14.7

Weight Flow, lb./min. 7.4

Std. cu. ft./min. (14.7 PSIA, 60F - Dry) 100.6

Inlet Pressure, PSIA 14.7

Inlet Temperature, °F 100

Relative Humidity, (%) 100

Molecular Weight 27.90

Inlet Volume, CFM 108.3

Discharge Pressure 19.7 PSIA

Operating Horsepower

DESIGN:

Manufacturer

Model

Type

Speed RPM

Outlet Velocity

Rotation (viewed from shaft end)

Casing Material C.S.

Impeller Material C.S.

Shaft Material C.S.

Inlet Nozzle Size

Discharge Nozzle Size

Discharge Position (observed from shaft end)

DRIVE:

Type (direct, v-belt, etc.)

Guard

DRIVER BY: Vendor

Type

Manufacturer

Mounted By

Horsepower

RPM

Enclosure

Volts/Phase/Cycles 120V - 1 PH - 60 CY

ACCESSORY EQUIPMENT:

Base Plate, CPLG

Form No. 303

Reproduced from best available copy.

JACOBS ENGINEERING CO. PAGE____ OF____ PAGES

CENTRIFUGAL PUMP DATA SHEET

PROJECT NO. 27-1656 ITEM NO. P-2
NOTE: ○ = INFORMATION TO BE COMPLETED BY PURCHASER; ☐ BY VENDOR
SPECIFICATION NO. ____
DESIGN ○ : API 610____, AVS____, OTHER____
DATE 2/21/77 REVISION A

FOR EPA SITE____
UNIT____ SERVICE Feed Slurry Pump
NO. PUMPS REQ'D 2 NO. MOTORS REQ'D____ ITEM NO.____ PROVIDED BY____ MTD BY____
NO. TURBINES REQ'D____ ITEM NO.____ PROVIDED BY____ MTD BY____
PUMP MFR____ SIZE AND TYPE____ SERIAL NO.____

OPERATING CONDITIONS, EACH PUMP

LIQUID Sludge, Oil, and water slurry(1) U.S. GPM at PT, NOR. 12.3 RATED 13.5
DISCH. PRESS., PSIG 40
PT, F, NOR. amb. MAX 100 SUCT. PRESS., PSIG MAX. 0 RATED____
SP.GR. at PT 1.23 DIFF. PRESS., PSI 40
VAP. PRESS. at PT, PSIA____ DIFF. HEAD, FT____
VIS. at PT, Ssu____ CP 3.5 NPSHA, FT 8
CORR/EROS. CAUSED BY Sand HYD. HP____

PERFORMANCE

PROPOSAL CURVE NO.____
RPM____ NPSHR (WATER)____
EFF.____ BHP RATED____
MAX. BHP RATED IMP____
MAX. HEAD RATED IMP____
MIN. CONTINUOUS GPM____
ROTATION (VIEWED FROM CPLG END)____

CONSTRUCTION

NOZZLES	SIZE	RATING	FACING	LOCATION
SUCTION				
DISCHARGE				

CASE-MOUNT: ☐ CENTERLINE ☐ FOOT ☐ BRACKET ☐ VERT. (TYPE)____
-SPLIT: ☐ AXIAL ☐ RAD; TYPE VOLUTE ☐ SGL ☐ DBL ☐ DIFFUSER
-PRESS: ☐ MAX. ALLOW.____ PSIG____ °F; ☐ HYDRO TEST____ PSIG
-CONNECT: ☐ VENT ☐ DRAIN ☐ GAGE
IMPELLER DIA.: ☐ RATED____ ☐ MAX.____, ☐ TYPE:____
MOUNT: ☐ BETWEEN BRGS ☐ OVERHUNG
BEARINGS-TYPE: ☐ RADIAL____ ☐ THRUST____
LUBE: ☐ RING OIL ☐ FLOOD ☐ OIL MIST ☐ FLINGER ☐ PRESSURE
COUPLING: ☐ MFR____ ☐ MODEL____ ○ GUARD____
DRIVER HALF MTD BY: ☒ PUMP MFR ○ DRIVER MFR ○ PURCHASER
PACKING: ☐ MFR & TYPE____ ☐ SIZE/NO. OF RINGS____
MECH. SEAL: ☐ MFR & MODEL____ API CLASS. CODE____
☐ MFR CODE____

SHOP TESTS

○ NON-WIT. PERF. ○ WIT. PERF.
○ NON-WIT. HYDRO ○ WIT. HYDRO
○ NPSH REQ'D. ○ WIT. NPSH
○ SHOP INSPECTION
○ DISMANT. & INSP. AFTER TEST
○ OTHER____

MATERIALS

CASE/TRIM CLASS ○____ (SEE API 610)

I –CAST IRON	CASE	C.S.
B –BRONZE	IMPELLER	C.S.
S –STEEL	INNER CASE PARTS	
C –11-13% CHROME	SLEEVE (PACKED)	
A –ALLOY	SLEEVE (SEAL)	
h –HARDENED	WEAR PARTS	
f –FACED	SHAFT	
X –		

BASEPLATE: ☐____

MOTOR DRIVER

HP____ RPM____ FRAME____
MFR____
TYPE____ INSUL.____
ENC.____ TEMP RISE C____
VOLTS/PHASE/CYCLES 440/3/60
BEARINGS____ LUBE____
FULL LOAD AMPS____
LOCKED ROTOR AMPS____
○ VHS ○ VSS____
VERT. THRUST CAP., LB.____

AUXILIARY PIPING

○ C.W. PIPE PLAN____ ○ CU; ○ S.S.; ○ TUBING, ○ PIPE____
☐ TOTAL COOLING WATER REQ'D, GPM____ ○ SIGHT F.I. REQ'D.
○ PACKING COOLING INJECTION REQ'D: ☐ TOTAL GPM ☐ PSIG
○ SEAL FLUSH PIPE PLAN____ ○ C.S. ○ S.S. ○ TUBING ○ PIPE____
○ EXTERNAL SEAL FLUSH FLUID____ ☐ GPM____ ☐ PSIG____
○ AUXILIARY SEAL PLAN____ ○ C.S. ○ S.S. ○ TUBING ○ PIPE____
○ AUX. SEAL QUENCH FLUID____

VERTICAL PUMPS

PIT OR SUMP DEPTH ○____
MIN. SUBMERGENCE REQ'D. ☐____
COLUMN PIPE: ☐ FLANGED ☐ THREADED
LINE SHAFT: ☐ OPEN ☐ ENCLOSED
BRGS: ☐ BOWL____ ☐ LINE SHAFT____
BRG. LUBE ☐ WATER ☐ OIL ☐ GREASE
FLOAT & ROD ○ C.S. ○ S.S. ○ BRZ ○ NONE
FLOAT SWITCH ☐____
PUMP THRUST, LB ☐ UP____ ☐ DOWN____

APPROX. WT, PUMP & BASE____
MOTOR____ TURBINE____

(1) Composition wt %: Oil = 27.16%, H_2O = 53.79%, Solids = 19.05%

JACOBS ENGINEERING CO. PAGE____ OF____ PAGES

CENTRIFUGAL PUMP DATA SHEET

NOTE: ○ = INFORMATION TO BE COMPLETED BY PURCHASER; ☐ BY VENDOR

DESIGN ○ : API 610____, AVS____, OTHER____

PROJECT NO. 27-1656 ITEM NO. P-3

SPECIFICATION NO.

DATE 2/21/77 REVISION A

FOR EPA SITE —

UNIT____ SERVICE Centrifuged Extract Pump

NO. PUMPS REQ'D 2 NO. MOTORS REQ'D____ ITEM NO.____ PROVIDED BY____ MTD BY____

NO. TURBINES REQ'D____ ITEM NO.____ PROVIDED BY____ MTD BY____

PUMP MFR____ SIZE AND TYPE____ SERIAL NO.____

OPERATING CONDITIONS, EACH PUMP

LIQUID Oil, Water, Acetone Mixture (1) U.S. GPM at PT, NOR. 53.18 RATED 58.50

DISCH. PRESS., PSIG 40

PT, F, NOR. 100 MAX. 100 SUCT. PRESS., PSIG MAX. 0 RATED____

SP.GR. at PT 0.83 DIFF. PRESS., PSI 40

VAP. PRESS. at PT, PSIA 3.49 DIFF. HEAD, FT____

VIS. at PT, Ssu____ CP 0.72 NPSHA, FT 8

CORR/EROS. CAUSED BY____ HYD. HP____

PERFORMANCE

PROPOSAL CURVE NO.____

RPM____ NPSHR (WATER)____

EFF.____ BHP RATED____

MAX. BHP RATED IMP____

MAX. HEAD RATED IMP____

MIN. CONTINUOUS GPM____

ROTATION (VIEWED FROM CPLG END)____

CONSTRUCTION

NOZZLES	SIZE	RATING	FACING	LOCATION
SUCTION				
DISCHARGE				

CASE-MOUNT: ☐ CENTERLINE ☐ FOOT ☐ BRACKET ☐ VERT. (TYPE)____

-SPLIT: ☐ AXIAL ☐ RAD; TYPE VOLUTE ☐ SGL ☐ DBL ☐ DIFFUSER

-PRESS: ☐ MAX. ALLOW.____ PSIG____ °F; ☐ HYDRO TEST____ PSIG

-CONNECT: ☐ VENT ☐ DRAIN ☐ GAGE

IMPELLER DIA.: ☐ RATED____ ☐ MAX.____, ☐ TYPE:____

MOUNT: ☐ BETWEEN BRGS ☐ OVERHUNG

BEARINGS-TYPE: ☐ RADIAL____ ☐ THRUST____

LUBE: ☐ RING OIL ☐ FLOOD ☐ OIL MIST ☐ FLINGER ☐ PRESSURE

COUPLING: ☐ MFR____ ☐ MODEL____ ○ GUARD____

DRIVER HALF MTD BY: ☒ PUMP MFR ○ DRIVER MFR ○ PURCHASER

PACKING: ☐ MFR & TYPE____ ☐ SIZE/NO. OF RINGS____

MECH. SEAL: ☐ MFR & MODEL____ API CLASS. CODE____

☐ MFR CODE____

SHOP TESTS

○ NON-WIT. PERF. ○ WIT. PERF.

○ NON-WIT. HYDRO ○ WIT. HYDRO

○ NPSH REQ'D. ○ WIT. NPSH

○ SHOP INSPECTION

○ DISMANT. & INSP. AFTER TEST

○ OTHER____

MOTOR DRIVER

HP____ RPM____ FRAME____

MFR____

TYPE____ INSUL.____

ENC.____ TEMP RISE C____

VOLTS/PHASE/CYCLES 440/3/60

BEARINGS____ LUBE____

FULL LOAD AMPS____

LOCKED ROTOR AMPS____

○ VHS ○ VSS____

VERT. THRUST CAP., LB.____

MATERIALS

CASE/TRIM CLASS ○____ (SEE API 610)

I	–CAST IRON	CASE	C.S.
B	–BRONZE	IMPELLER	C.S.
S	–STEEL	INNER CASE PARTS	
C	–11-13% CHROME	SLEEVE (PACKED)	
A	–ALLOY	SLEEVE (SEAL)	
h	–HARDENED	WEAR PARTS	
f	–FACED	SHAFT	
X	–		

BASEPLATE: ☐____

VERTICAL PUMPS

PIT OR SUMP DEPTH ○____

MIN. SUBMERGENCE REQ'D. ☐____

COLUMN PIPE: ☐ FLANGED ☐ THREADED

LINE SHAFT: ☐ OPEN ☐ ENCLOSED

BRGS: ☐ BOWL____ ☐ LINE SHAFT____

BRG. LUBE ☐ WATER ☐ OIL ☐ GREASE

FLOAT & ROD ○ C.S. ○ S.S. ○ BRZ ○ NONE

FLOAT SWITCH ☐

PUMP THRUST, LB ☐ UP____ ☐ DOWN____

AUXILIARY PIPING

○ C.W. PIPE PLAN____ ○ CU; ○ S.S.; ○ TUBING, ○ PIPE____

☐ TOTAL COOLING WATER REQ'D, GPM____ ○ SIGHT F.I. REQ'D____

○ PACKING COOLING INJECTION REQ'D: ☐ TOTAL GPM ☐ PSIG

○ SEAL FLUSH PIPE PLAN____ ○ C.S. ○ S.S. ○ TUBING ○ PIPE____

○ EXTERNAL SEAL FLUSH FLUID____ ☐ GPM____ ☐ PSIG____

○ AUXILIARY SEAL PLAN____ ○ C.S. ○ S.S. ○ TUBING ○ PIPE____

○ AUX. SEAL QUENCH FLUID____

APPROX. WT, PUMP & BASE____

MOTOR____ TURBINE____

(1) Composition wt %: Oil = 8.21%, H_2O = 16.25, Acetone = 75.54

FORM 104

JACOBS ENGINEERING CO.

PAGE_____OF_____PAGES

CENTRIFUGAL PUMP DATA SHEET

NOTE: ○ = INFORMATION TO BE COMPLETED BY PURCHASER; ☐ BY VENDOR

DESIGN ○ : API 610____, AVS____, OTHER_____

PROJECT NO. 27-1656 ITEM NO. P-4

SPECIFICATION NO._____

DATE 2/21/77 REVISION A

FOR EPA SITE_____

UNIT_____ SERVICE Aqueous Acetone Pump

NO. PUMPS REQ'D_____ NO. MOTORS REQ'D_____ ITEM NO._____ PROVIDED BY_____ MTD BY_____

NO. TURBINES REQ'D_____ ITEM NO._____ PROVIDED BY_____ MTD BY_____

PUMP MFR_____ SIZE AND TYPE_____ SERIAL NO._____

OPERATING CONDITIONS, EACH PUMP

LIQUID 10 wt% Aqueous Acetone Soln. U.S. GPM at PT, NOR. 5.37 RATED 5.43

DISCH. PRESS., PSIG 40

PT, F, NOR. 100 MAX. 100 SUCT. PRESS., PSIG MAX. 0 RATED_____

SP.GR. at PT 0.97 DIFF. PRESS., PSI 40

VAP. PRESS. at PT, PSIA 3.47 DIFF. HEAD, FT_____

VIS. at PT, Ssu_____ CP 1.1 NPSHA, FT 8

CORR/EROS. CAUSED BY_____ HYD. HP_____

CONSTRUCTION

NOZZLES	SIZE	RATING	FACING	LOCATION
SUCTION				
DISCHARGE				

CASE-MOUNT: ☐ CENTERLINE ☐ FOOT ☐ BRACKET ☐ VERT. (TYPE)_____

-SPLIT: ☐ AXIAL ☐ RAD; TYPE VOLUTE ☐ SGL ☐ DBL ☐ DIFFUSER

-PRESS: ☐ MAX. ALLOW._____ PSIG_____ °F; ☐ HYDRO TEST_____ PSIG

-CONNECT: ☐ VENT ☐ DRAIN ☐ GAGE

IMPELLER DIA.: ☐ RATED_____ ☐ MAX._____, ☐ TYPE:_____

MOUNT: ☐ BETWEEN BRGS ☐ OVERHUNG

BEARINGS-TYPE: ☐ RADIAL_____ ☐ THRUST_____

LUBE: ☐ RING OIL ☐ FLOOD ☐ OIL MIST ☐ FLINGER ☐ PRESSURE

COUPLING: ☐ MFR_____ ☐ MODEL_____ ○ GUARD_____

DRIVER HALF MTD BY: ☒ PUMP MFR ○ DRIVER MFR ○ PURCHASER

PACKING: ☐ MFR & TYPE_____ ☐ SIZE/NO. OF RINGS_____

MECH. SEAL: ☐ MFR & MODEL_____ API CLASS. CODE_____

☐ MFR CODE_____

MATERIALS

CASE/TRIM CLASS ○_____ (SEE API 610)

I —CAST IRON	CASE	C.S.
B —BRONZE	IMPELLER	C.S.
S —STEEL	INNER CASE PARTS	
C —11-13% CHROME	SLEEVE (PACKED)	
A —ALLOY	SLEEVE (SEAL)	
h —HARDENED	WEAR PARTS	
f —FACED	SHAFT	
X —		

BASEPLATE: ☐_____

AUXILIARY PIPING

○ C.W. PIPE PLAN_____ ○ CU; ○ S.S.; ○ TUBING, ○ PIPE_____

☐ TOTAL COOLING WATER REQ'D, GPM_____ ○ SIGHT F.I. REQ'D_____

○ PACKING COOLING INJECTION REQ'D: ☐ TOTAL GPM ☐ PSIG

○ SEAL FLUSH PIPE PLAN_____ ○ C.S. ○ S.S. ○ TUBING ○ PIPE_____

○ EXTERNAL SEAL FLUSH FLUID_____ ☐ GPM_____ ☐ PSIG_____

○ AUXILIARY SEAL PLAN_____ ○ C.S. ○ S.S. ○ TUBING ○ PIPE_____

○ AUX. SEAL QUENCH FLUID_____

PERFORMANCE

PROPOSAL CURVE NO._____

RPM_____ NPSHR (WATER)_____

EFF._____ BHP RATED_____

MAX. BHP RATED IMP_____

MAX. HEAD RATED IMP_____

MIN. CONTINUOUS GPM_____

ROTATION (VIEWED FROM CPLG END)_____

SHOP TESTS

○ NON-WIT. PERF. ○ WIT. PERF.

○ NON-WIT. HYDRO ○ WIT. HYDRO

○ NPSH REQ'D. ○ WIT. NPSH

○ SHOP INSPECTION

○ DISMANT. & INSP. AFTER TEST

○ OTHER_____

MOTOR DRIVER

HP_____ RPM_____ FRAME_____

MFR_____

TYPE_____ INSUL_____

ENC_____ TEMP RISE C_____

VOLTS/PHASE/CYCLES 440/3/60

BEARINGS_____ LUBE_____

FULL LOAD AMPS_____

LOCKED ROTOR AMPS_____

○ VHS ○ VSS_____

VERT. THRUST CAP., LB._____

VERTICAL PUMPS

PIT OR SUMP DEPTH ○_____

MIN. SUBMERGENCE REQ'D. ☐_____

COLUMN PIPE: ☐ FLANGED ☐ THREADED

LINE SHAFT: ☐ OPEN ☐ ENCLOSED

BRGS: ☐ BOWL_____ ☐ LINE SHAFT_____

BRG. LUBE ☐ WATER ☐ OIL ☐ GREASE

FLOAT & ROD ○ C.S. ○ S.S. ○ BRZ ○ NONE

FLOAT SWITCH ☐_____

PUMP THRUST, LB ☐ UP_____ ☐ DOWN_____

APPROX. WT, PUMP & BASE_____

MOTOR_____ TURBINE_____

FORM 104

JACOBS ENGINEERING CO. **VESSEL SPECIFICATION**

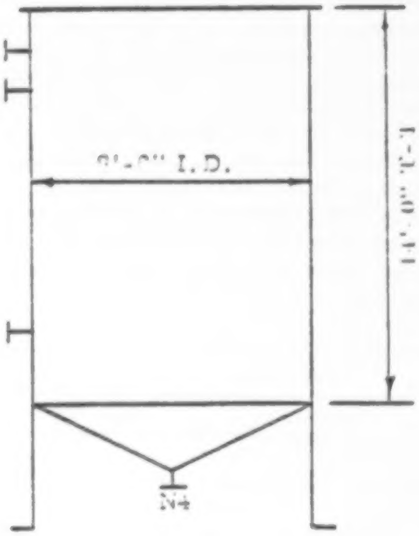
CUSTOMER	EPA	PROJECT	27-1656	ITEM	V-1, V-2
LOCATION		DATE	3-1-77	JOB	27-1656
SERVICE	Slurry Tank	BY	KT	PAGES	PAGE

NO	SIZE	LENGTH	CODE	SPECIFICATION	
PSW ATM	TSW 150 F	CORROSION 1/8"	SR	XR	

PART	MATERIAL	DESCRIPTION
SHELL	C.S.	
HEADS	C.S.	Cone
SUPPORTS	C.S.	— LEGS
MANHOLES		HINGE — DAVIT
NOZZLES	C.S.	
COUPLINGS	C.S.	
INTERNALS		
CLIPS		LADDER — PLATFORM
RINGS		INSULATION — VACUUM
PAINT		
DAVIT		

NOZZLES

	SERVICE	NO	SIZE	RATING	FACING
N1	Slurry In				
N2	High Level				
N3	Low Level				
N4	Slurry Out				



REMARKS Open top mixing tank.
(2 required.)

NO	DATE	REVISION

FORM 1361

JACOBS ENGINEERING CO. **VESSEL SPECIFICATION**

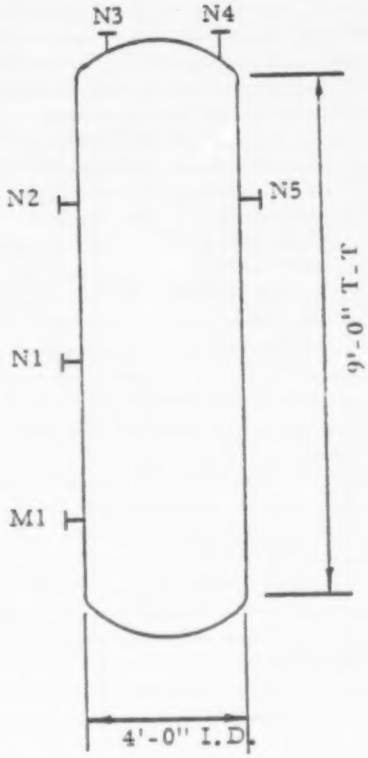
CUSTOMER EPA
PROJECT 27-1656 ITEM V-3
LOCATION
DATE 3-1-77 JOB 27-1656
SERVICE Acetone Accumulator
BY KJ PAGES PAGE
NO SIZE LENGTH CODE ASME SPECIFICATION
PSW 25 PSIG TSW 300 F CORROSION 1/8" SR XR

PART	MATERIAL	DESCRIPTION
SHELL	C.S.	
HEADS	C.S.	SEMIELLIP—DISHED
SUPPORTS		SKIRT—SADDLES—LEGS
MANHOLES	C.S.	HINGE—DAVIT
NOZZLES	C.S.	
COUPLINGS		
INTERNALS		
CLIPS		LADDER—PLATFORM
RINGS		INSULATION—VACUUM
PAINT		
DAVIT		

NOZZLES

	SERVICE	NO	SIZE	RATING	FACING
N1	Vent Gas				
N2	Liquid In				
N3	High Level				
N4	Low Level				
N5	Liquid Out				
M1	Manhole				

REMARKS



NO	DATE	REVISION

FORM 1261

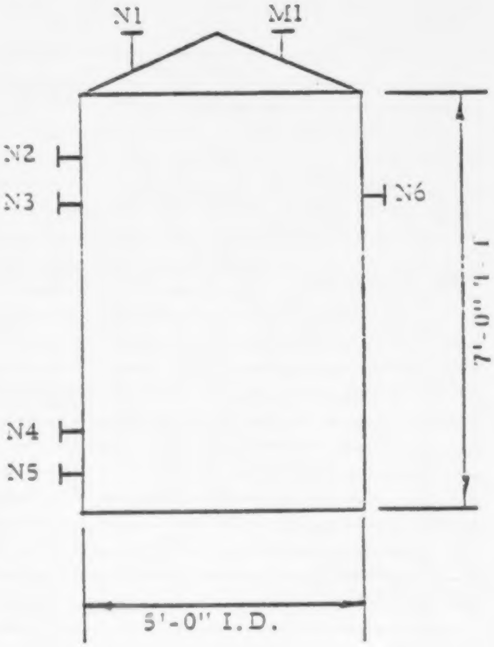
JACOBS ENGINEERING CO. **VESSEL SPECIFICATION**

CUSTOMER EPA PROJECT 27-1656 ITEM V-4
LOCATION DATE 3-1-77 JOB 27-1656
SERVICE Decanter Tank BY KJ PAGES PAGE
NO SIZE LENGTH CODE ASME SPECIFICATION
PSW 25 PSIG TSW 250 F CORROSION 1/8" SR XR

PART	MATERIAL	DESCRIPTION
SHELL	C.S.	
HEADS		SEMIELLIP—DISHED
SUPPORTS		SKIRT—SADDLES—LEGS
MANHOLES	C.S.	HINGE—DAVIT
NOZZLES	C.S.	
COUPLINGS		
INTERNALS		
CLIPS		LADDER—PLATFORM
RINGS		INSULATION—VACUUM
PAINT		
DAVIT		

NOZZLES

	SERVICE	NO	SIZE	RATING	FACING
N1	Vent				
N2	Liquid In				
N3	High Level				
N4	Low Level				
N5	Waste Water Out				
N6	Oil Out				
M1	Manhole				



REMARKS

NO	DATE	REVISION

FORM 1381

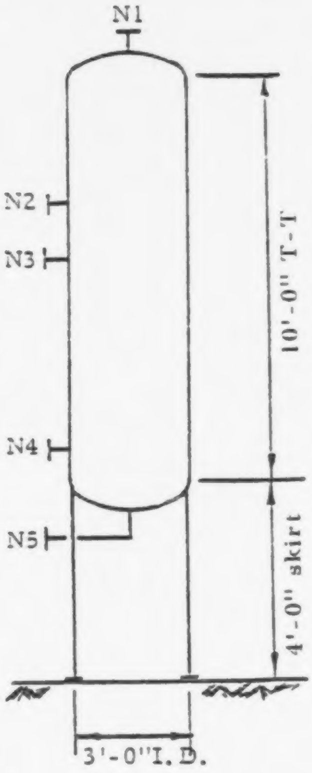
JACOBS ENGINEERING CO. **VESSEL SPECIFICATION**

CUSTOMER EPA
PROJECT 27-1656 ITEM V-5
LOCATION
DATE 3-1-77 JOB 27-1656
SERVICE Extract Surge Tank
BY KJ PAGES PAGE
NO SIZE LENGTH CODE ASME SPECIFICATION
PSW 25 PSIG TSW 300 F CORROSION 1/8" SR XR

PART	MATERIAL	DESCRIPTION
SHELL	C.S.	
HEADS	C.S.	SEMIELLIP—DISHED
SUPPORTS	C.S.	SKIRT—SADDLES—LEGS
MANHOLES	C.S.	HINGE—DAVIT
NOZZLES		
COUPLINGS		
INTERNALS		
CLIPS		LADDER—PLATFORM
RINGS		INSULATION—VACUUM
PAINT		
DAVIT		

NOZZLES

	SERVICE	NO	SIZE	RATING	FACING
N1	Vent				
N2	Extract In				
N3	High Level				
N4	Low Level				
N5	Extract Out				



REMARKS

NO	DATE	REVISION

FORM 1361

3/1/77
By KJ

X-1, X-2

EPA
27-1656

SCREW CONVEYORS

Need two screw conveyors to transport solids within the process, the first to transport solids from the centrifuge to the dryer; the second to transport dried solids from the dryer to a stack.

Specify for each conveyor a 20 ft long 12" diameter unit.

For vapor-tight operations take $400/ft.

Cost for conveyors = 2 x 20 x 400 = $16,000.

TABLE E-1

TYPICAL PROPERTIES OF ETHLY ALCOHOL (5)

	Absolute	95%
Apparent ignition temp. in air	371-427C	
Boiling point	78.4C	78.2C
Electrical conductivity	1.35 x 10^9 cecip. ohms (25C)	
Explosive limits in air	3.7-13.7%	
Flash point (ASTM Open Cup)	18.3C (65F)	14°C (57F)
Freezing point	-114/4°C	
Heat of combustion	328 kg cal./mol	
Heat of fusion	24.9 cal./g	
Heat of vaporization at B.P.	204 cal./g	
Melting point	-116°C	
Refractive index at 15°C	1.3633	1.3651
Specific gravity at 20/20°C	0.7904	0.8089-08128
Specific heat at 25°C	0.581 cal./g	0.618 cal./g (23°C)
Surface tension at 20°C	22.3 dynes/cm	22.8dynes/cm (20°C)
Viscosity at 20°C	0.0122 poise	0.0141 poise (20°C)
Vapor pressure at 20°C	43.6 mm	43.0 mm (20°C)
Weight per gallon at 20°C	6.60 lbs.	6.73 lbs. (20°C)

Typical Specifications, Chemically Pure, 96%

Acidity, free acid as scetic	0.0014 gm. per 100 cc. max.
Boiling point	78.2°C
Distillation range	100% between 77-80°C
Flash point	62°F (aaprox.)
Nonvolatile matter	Not more than 0.0025 g per 100 cc
Odor	Free from foreign odors when tested at high or low proof
Purity	96% ethyl alcohol by vol., min.
Reducing substances	Not less than 45 min. permanganate time
Specific gravity at 15.6/15.6°C	0.8121
Solubility in water	In all proportions and without turbidity

TABLE E-2

TYPICAL PROPERTIES OF ETHYL ACETATE (5)

	(99 to 100%) acetic ether grade
Acidity (as acetic)	0.01% by wt, max.
Blush resistance at 90°F (10% 1/2 sec. R.S. nitrocellulose solution	Clear 55% Relative humidity Blush 60%
Coefficient of expansion per 1°F	0.00074
per 1°C	0.000133
Color	Water-white
Dilution ratio	
Toluol	3.0
Petroleum naphtha	1.0
Distillation range	75 to 80°C
Electrical conductivity at 25°C	3.2×10^{-7} recip ohms
Evap. rate at 95°F (in min.)	
5%	1/4
25%	1-1/2
50%	3-3/4
75%	6-1/2
90%	9-1/4
95%	10-1/4
Explosive limits	2.26-11.4%
Flash point	0.5°C
Freezing point	-82.4°C
Heat of combustion	538 kg. cal/mole
Heat ov vaporization at 0°C	102 cal/gm
at 80°C	102.9 cal/gm
Non-volatile matter	0.003 gram when 100 cc. max.
	(99 to 100%)
Refractive index at 19°C	1.3722
Solubility in water at 20°C	7.9% by wt
Solubility of water in solvent at 20°C	3.0% by wt
Specific gravity at 20/20°C	0.899 to 0.902
Surface tension at 20°C	24.3 dynes/cm
Viscosity at 21.4°C	0.00442 poises
Vapor pressure at 20/20°C	72.8 mm Hg
Weight per gal at 20°C	7.5 lbs

TABLE E-3

TYPICAL PROPERTIES OF METHYL ALCOHOL (5)

Acidity	0.01% max. calculated as formic acid
Boilint point (at 760 mm)	64.5°C
Average coefficient of cubical expansion from 0°C to 61°C	0.0012
Critical temperature	240°C
Critical pressure	78.7 atm.
Color	Water-white
Dielectric constant at 20°C	31.2
Distillation range	64° - 66°C
Electrical conductivity at 18°C	4.4×10^{-7} reciprocal ohm
Flash point	14°C
Heat of combustion	170.9 kg cal./mol.
Heat of fusion	23.6 cal./g.
Latent heat of vaporization at B.P.	262.8 cal./g.
Melting point	-97°C
Purity	99.8 - 99.9%
Specific gravity at 20/4°C	0.792
Specific heat (vapor) at 77°C	0.39 cal./g.
Refractive index at 20°C	1.329
Surface tension at 20°C	22.6 dynes/cm
Vapor pressure at 0°C	26.6 mm
20	96.0
40	260.5
60	025.0
Viscosity at 20°C	0.00593 poise
Weight per gallon at 20°C	6.59 lbs.

TABLE E-4

TYPICAL PROPERTIES OF METHYL ETHYL KETONE (5)

Boiling point at 760 mm	79.6°C
Coefficient of expansion	0.00076 per °F
Electrical Conductivity	1.0×10^{7} ohms at 25°C
Explosive limits	1.97% - 10.2%
Flash point (Tag Closed Cup)	25°F
Freezing point	-86.4°C
Heat of combustion	582 Cal./mole
Latent heat of Vaporization at 20°C	106.0 cal./g.
Refractive Indes, N 20/D	1.3788
Solubility of water in solvent	23.4% by wt.
Specific gravity at 20/20°C	0.805-0.807
Specific heat	0.55 cal./g.
Surface tension	
0°C 26.9 dynes/sq cm	
20 24.6	
40 22.3	
75 18.4	
Viscosity at 15°C	0.00423 poise
Weight per gallon at 20°C	6.72 lbs.
Acidity (as acetic)	0.0025 by wt. (max.)
Distillation range (ASTM)	70°-80.5°C
Non-volatile matter	3 mg. per 100 ml. (max.)
Purity	99%

TABLE E-5

TYPICAL PROPERTIES OF TRIETHYL AMINE (5)

Boiling point	89.5°C
Critical solution temperature (in water)	18°C
Dissociation constant	6.4×10^{-4}
Flash point (open cup)	20°F
Heat of combustion	10,248 cal./g.
Heat of solution in water	10,040 cal./mol of solute at infinite dilution
Melting point	-114.8°C
Specific gravity at 20/20°C	0.730
Refractive index at 20°C	1.4003
Weight per gallon (20°C)	6.1 lbs.
Color	Water-white
Distillation range	
Initial boiling point	Not below 85°C
Final boiling point	Not above 91°C
Purity	98.5%, min.
Water insoluble (20-30°C)	None

APPENDIX F

BASIC EXTRACTION SLUDGE TREATMENT (BEST) PROCESS

This section includes a discussion of the various aspects of the BEST Process. The items covered are:

Process Description
Process Flow Diagram
Reasons for Choice of TEA as the Solvent
Capital Costs
Estimated Operating Costs
Major Equipment List
Isometric View of BEST System

The data and information were supplied by Resources Conservation Co., the supplier of the BEST system. The B.E.S.T. system is an existing phase separation system for recovery of small quantities of oil from municipal sludges. It has not been tested on bench scale or pilot plant for the waste streams from petroleum refining operations. The following pages outline the process.

BEST PROCESS DESCRIPTION

Sludge is continuously metered to the system and mixed with recirculated cold solvent in a ratio of approximately six parts solvent to one part sludge. If lime or sodium hydroxide pretreatment is required to improve process efficiency or product quality, it is added to the input sludge.

The sludge/solvent mixture is then cooled to 40 F (4 C) and fed to a centrifuge for solid/liquid separation. 98 percent or more of the system solids feed is captured by the centrifuge and discharged as a solvent-wet cake. Up to 90 percent of the water is removed mechanically, without a phase change, and does not enter the dryer. The wet cake enters the continuously operating dryer which yields a cake dried to 95 percent solids at temperatures between 250 F (121 C) and 320 F (160 C). Solvent and water vapor from the dryer are then condensed and returned to the system. As mentioned above, the comparatively low operating temperatures required in the drying process result in energy savings and lower operating costs.

Most of the oil contained in the sludge feed is taken into solution with the solvent and is part of the liquid fraction (centrate) leaving the centrifuge at 40 F (4 C). The temperature of the centrate, composed of solvent, water and oil, is raised to 140 F (60 C) and separated into solvent and water fractions in the decanter. Colloidal solids, not initially captured in the centrifuge, agglomerate at the solvent/water interface in the decanter and are drawn off, cooled and returned to the centrifuge for removal.

The separated water in the decanter is continuously pumped to a water still where any residual solvent is steam stripped and returned to the system. The water in the still bottoms is cooled and available for return to the headwaters of the wastewater sewage treatment plant for discharge.

The separated solvent from the decanter is cooled to 15 F (-9 C) by recuperative and refrigerative heat exchangers and is recirculated to be mixed with the incoming sludge. A portion of the recirculated solvent is continuously bypassed to a solvent still where the oil is removed by steam stripping. The bypass rate is controlled to maintain a desired oil concentration in the recirculated solvent.

The mixture of oil and water remaining in the solvent still bottom is separated. The water is cooled and returned to the wastewater treatment plant or disposal with the water from the water still, and the separated oil is recovered for use.

REASONS FOR CHOICE OF TRIETHYLAMINE AS THE SOLVENT IN THE BEST PROCESS

The two primary reasons for choosing the chemical triethylamine (TEA) as the solvent for the BEST process are its water solubility characteristics and its ability to act as a conditioner with hard to dewater sludges. The enclosed solvent water solubility curve shows that, at fairly moderate temperatures and for a wide range of mixtures, the phase line separation between water and triethylamine is very definite. This allows the water in the sludge to be in solution with the solvent at temperatures below 65 F. Then, after mechanical separation of the solids, the mixture can be heated to above 65 F, and the water and TEA separated. Thus, a majority of the water can be removed from sludge without a phase change. Also, only a small amount of recycled solvent (3 percent at 100 F) needs to go through a phase change. These characteristics, as well as the low heat vaporization of TEA (133 Btu/lb), allow for the potential of very low energy use in separating the water, oil and solids in a sludge using triethylamine.

The ability of the solvent TEA to act as a conditioning agent to dramatically increase efficiencies of standard dewatering equipment is another major reason for its choice. A large number of laboratory and pilot plant tests have shown that cake solids are significantly increased, as well as increased centrate quality, after TEA is added to most sludges. This characteristic allows the efficiencies of standard dewatering equipment available for filtration and centrifugation to be significantly increased. Thus, costs are lowered both in capital, because of equipment size, and operating costs because of less energy for drying and less costs in recycle water treatment and chemical conditioning. The characteristic of TEA that allows oil to stay in the solvent is also beneficial as oil separation from the solids and water is desirable for most sludges.

Another major reason for choosing the solvent TEA rather than other solvents that have similar characteristics as far as solubility with water and conditioning effect on sludges, is that TEA is in wide use today throughout industry, and is commercially available from a number of chemical manufacturers. Approximately 10,000,000 pounds per year of triethylamine are used in areas as diverse as a solubilizer, intermediate, and pesticide for agricultural chemicals; as a corrosion inhibitor for industrial applications such as power boilers and field equipment in petroleum production; as a major ingredient in the production of various drugs such as penicillin and streptomycin in the drug and pharmaceutical industry; as hardening agents for resins and in the preparation of various ion exchange resins. The widespread existing use of TEA means that it is being handled by thousands of people each day, thus will not be likely to create a difficult handling problem for sludge dewatering and drying. Its widespread use also means that it will be available for many years at competitive prices.

Capital Costs

The estimated capital costs are order of magnitude costs and are for a fully installed and operating system. Thus, the cost includes all equipment, complete engineering, full installation and start-up, including operator training. Site preparation, including a pad for the process equipment and a building for the Control Room, Motor Control Center, Refrigeration Package and Boiler is not included in the cost estimate. The estimate size of the building required is 13' x 30' x 12' high, with an additional pad area required of 26' x 30'.

Completely designed plant with all equipment and installation design for erection, assembly and installation by others:

Estimated Price $2,170K

Estimated cost of erection, assembly and installation without building or foundations is $650K.

BEST ESTIMATED OPERATING COSTS

Assumptions:

Fuel Costs	$\$2.13/10^6$ BTU
Steam Costs	$\$2.50/10^6$ BTU (25% Eff)
Electric Power	20 mils/kWh
Manpower	$12/hr
Operation	24 hr/day, 360 days/year, 7 days/week
Maintenance Material	2% capital/year
Maintenance Labor	2% capital/year

Sludge Description:

Wastes from typical 200,000 Bbl per day refinery

Oil 27.2% =	1762 lbs/hr
Solids 19.0% =	1250 lbs/hr
Water 53.8% =	3528 lbs/hr

BEST Process Costs:

		$/Day
Thermal Energy	15,544 BTU/lb solids	$1165.80
Electrical Energy	.40 Kwh/lb solids	240.00
Chemicals (TEA Loss)	.0015 lb TEA/lb solids	45.00
Cooling Water	96 gals/lb solids	
Operating Manpower	4 manhours/shift	144.00
Maintenance Labor & Material	4% capital/year	244.00
Total $/day		$1838.00
Oil Recovery	41,998 #/day	

TABLE F-1 MAJOR EQUIPMENT LIST

80 Tons/Day Refinery Sludges - Jacobs Engineering

Item No.	Name	No. Reqd.	Capacity	Description/Specification
1	Centrifuge	1	120 GPM	Solid bowl, carbon steel construction, hard surfaced conveyor and discharge, vapor tight. Bird, Sharples or equivalent, Class I, Group D, Div. 1 motor and backdrive
2	Dryer	1	2.6×10^6 BTU/hr 585 ft^2 jacket area	Strong-Scott solidaire, carbon steel construction, steam heated, Class I, Group D, Div. 1 motor
3	Refrigeration System	1	100 Tons	Multistage centrifugal refrigeration compressor, condenser, brine chiller w/brine pump, controls, accessories and associated piping
4	Economizers	4	0.5×10^6 BTU/hr to 1.5×10^6 BTU/hr	Plate type heat exchangers, S.S. plates; ADV or equivalent
5	Chillers	2	0.6×10^6 BTU/hr 100-120 GPM	Tube-shell type heat exchangers S.S. construction

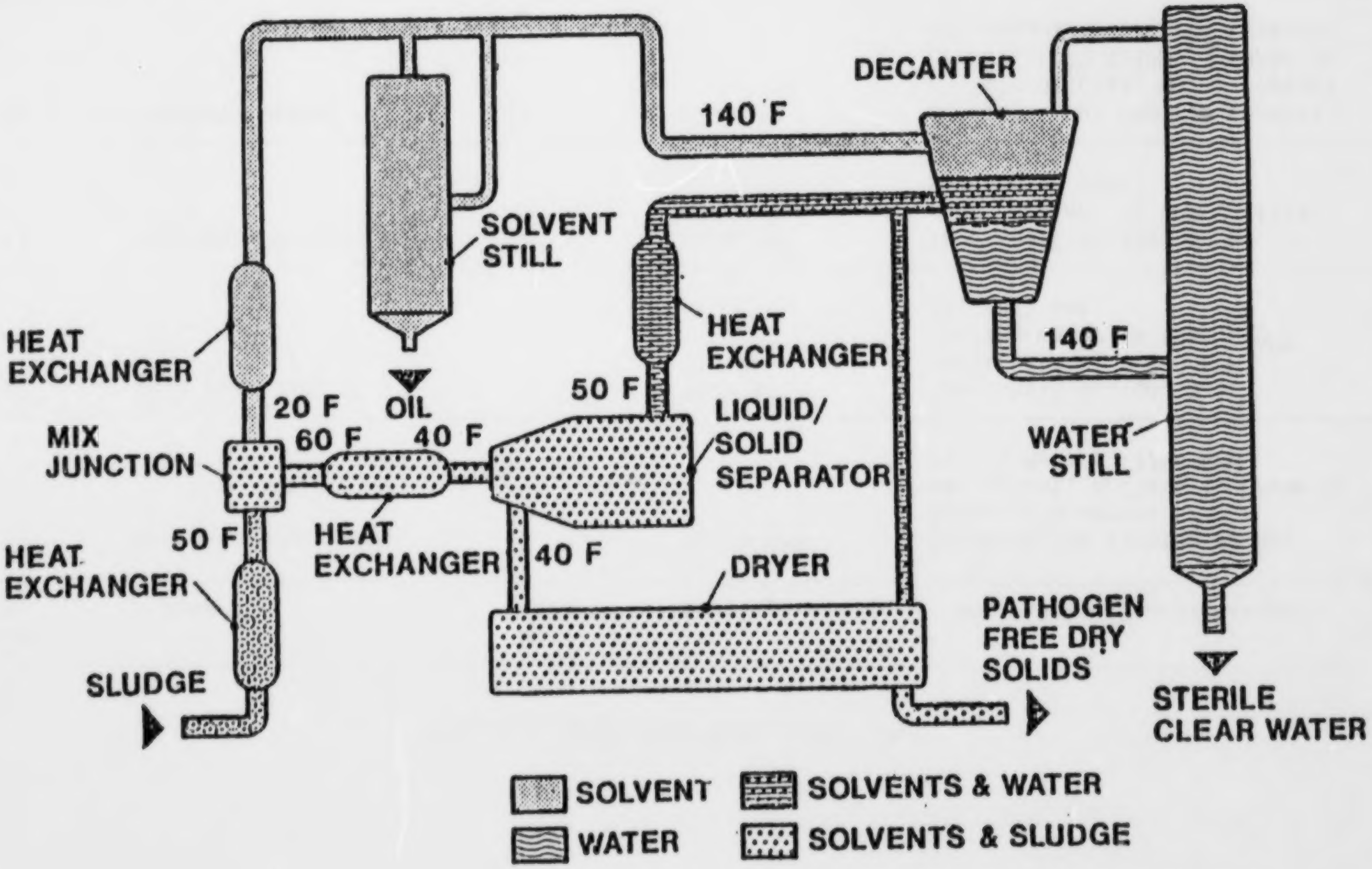
TABLE F-2 MAJOR EQUIPMENT LIST - Cont.

Item No.	Name	No. Reqd.	Capacity	Description/Specification
6	Water Still	1	21 GPM	Packed column, carbon steel shell, S.S. packing, redistribution plates and supports.
7	Solvent Still	1	200 GPM	Packed column, carbon steel shell, S.S. packing, redistribution plates and supports.
8	Sludge Pumps	2	15 GPM	Moyno, w/Class I, Group D, Div. 1 motor and variable speed drive w/pneumatic positioner
9	Centrate Pump	1	110 GPM	Centrifugal, end suction pump, cast iron, stainless steel trim, Worthington Model D-1000 or equivalent, W/7.5 HP, 3500 RPM motor, Class I, Group D, Div. 1
10	Solvent Recycle Pump	1	300 GPM	Centrifugal, end suction pump, cast iron, stainless steel trim, Worthington Model D-1000 or equivalent, W/15 HP, 3500 RPM motor, Class I, Group D, Div. 1

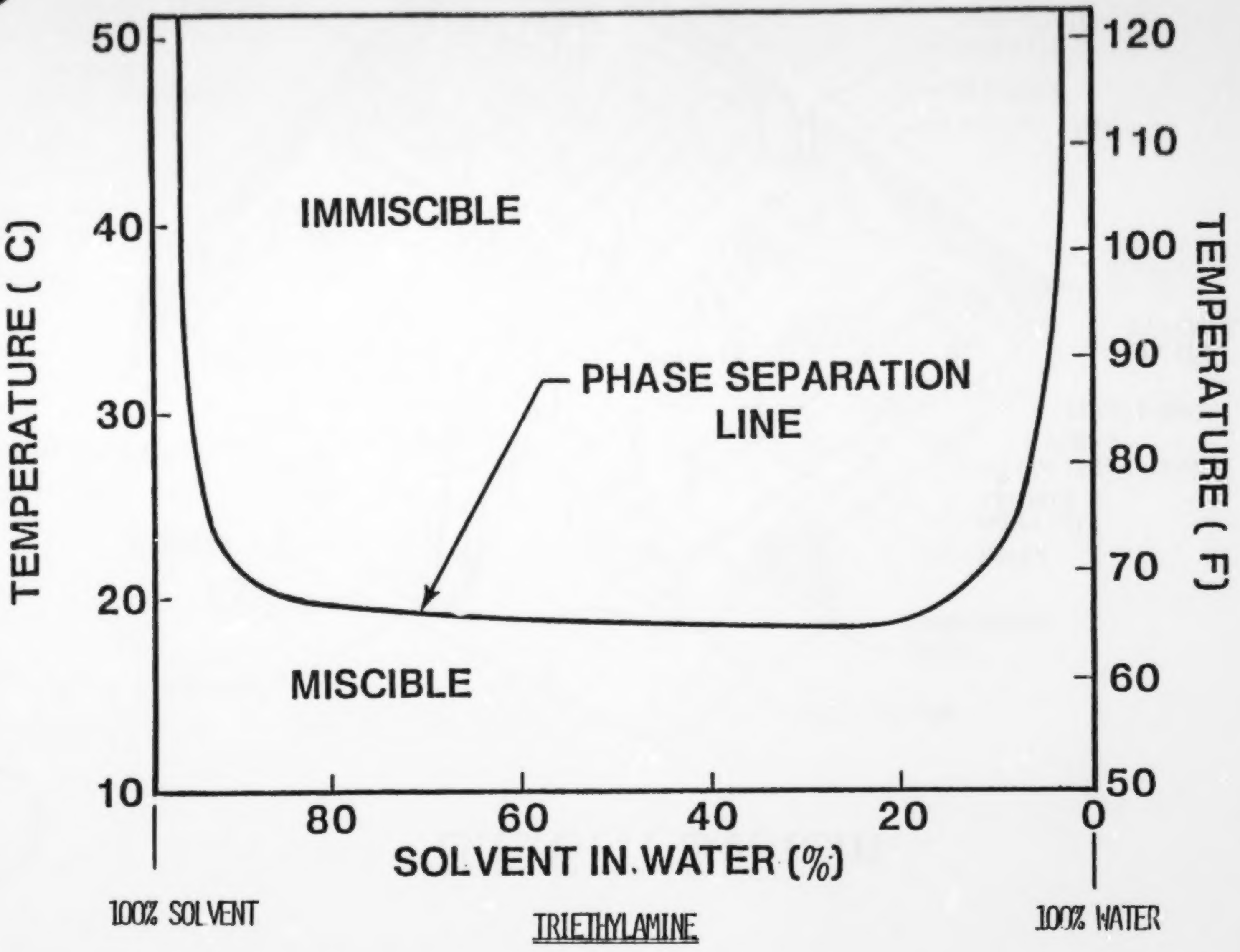
TABLE F-1 MAJOR EQUIPMENT LIST - Cont.

Item No.	Name	No. Reqd.	Capacity	Description/Specification
11	Miscellaneous Pumps	5	to 30 GPM	Regenerative turbine pumps, Aurora 150 series or equivalent, W/Class 1, Group D, Div. 1 Motors, 1750 RPM
12	Main Condenser	1	18×10^6 BTU/Hr	Tube-shell design, S.S. construction, 1,800 GPM cooling water in tube, 70^oF in, 90^oF out
13	Secondary Condenser	1	23×10^3 BTU/Hr	Tube-shell design, S. S. construction, 12 GPM chilled solvent in tube
14	Control System	1	-	Consisting of control console W/mimic display, motor control center, 2300 V/480V/3 PH/60 HZ and pneumatic process controls

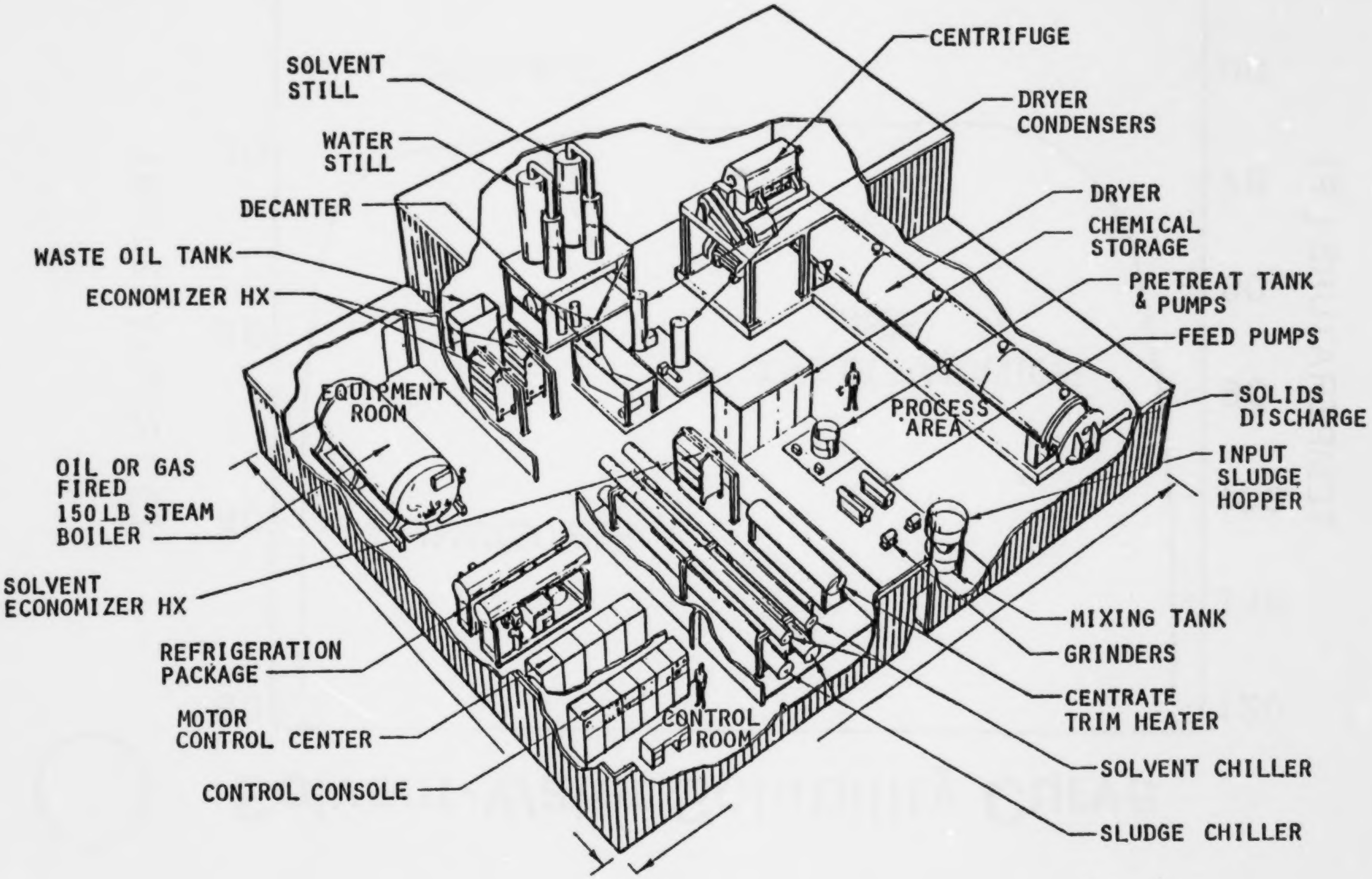
B. E. S. T. Process Flow


DECANTER
140 F
SOLVENT STILL
HEAT EXCHANGER
140 F
WATER STILL
HEAT EXCHANGER
20 F
OIL
50 F
LIQUID/ SOLID SEPARATOR
MIX JUNCTION
60 F
40 F
50 F
HEAT EXCHANGER
HEAT EXCHANGER
40 F
DRYER
SLUDGE
PATHOGEN FREE DRY SOLIDS
STERILE CLEAR WATER
SOLVENT
WATER
SOLVENTS & WATER
SOLVENTS & SLUDGE

Solvent-Water Solubility Curve



B.E.S.T. System


SOLVENT STILL
WATER STILL
DECANTER
WASTE OIL TANK
ECONOMIZER HX
EQUIPMENT ROOM
OIL OR GAS FIRED 150 LB STEAM BOILER
SOLVENT ECONOMIZER HX
REFRIGERATION PACKAGE
MOTOR CONTROL CENTER
CONTROL CONSOLE
CONTROL ROOM
CENTRIFUGE
DRYER CONDENSERS
DRYER
CHEMICAL STORAGE
PRETREAT TANK & PUMPS
FEED PUMPS
PROCESS AREA
SOLIDS DISCHARGE
INPUT SLUDGE HOPPER
MIXING TANK
GRINDERS
CENTRATE TRIM HEATER
SOLVENT CHILLER
SLUDGE CHILLER

APPENDIX G

DESIGN OF CALCINATION SYSTEM

This section develops the design and specifications for the calcination process. Discussion of the process and process schematics is included in Section 5. These specifications were supplied to vendors to obtain price quotations which form the basis for our cost estimates.

CALCINATION

1) Holding Tank

Total waste mass flow rate = 4746 lbs/hr

= 797328 lbs/week

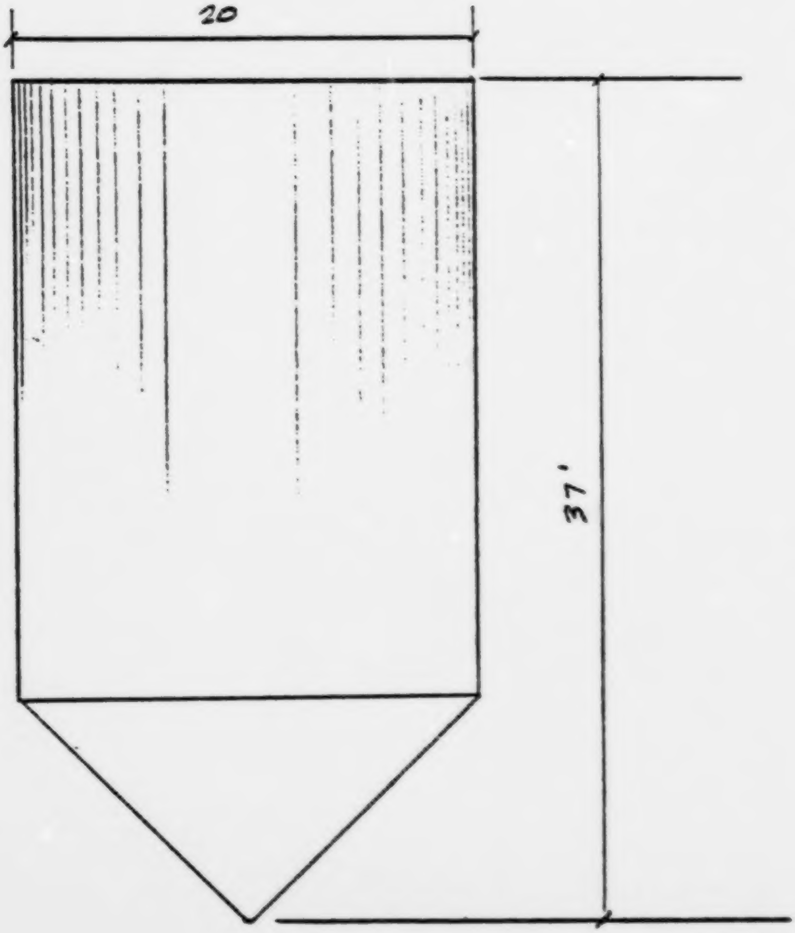
Assuming the specific gravity of waste feed = 1.1

Capacity of holding tank

$$= \frac{797328}{63 \times 1.1} = 11505 \text{ cu. ft.}$$

Diameter of holding tank = 20 feet

Height of holding tank = 37 feet



2) Centrifugation

Feed flow rate to the centrifuge = 4746 lbs/hr

= 68.5 cu. ft/hr = 1.14 cu.ft/mt

Assuming @ 95% solid removal in the centrifuge

@ 80% by wt. solids in the cake

$$SR = \frac{Sc\ (Si - Sc)}{Si\ (Ss - Sc)}$$

SR = Solids recovery, 95%

Sc = Solids in centrate

Si = Solids in influent, % by wt = 45%

Ss = Solids in discharge cake, % by wt = 80

$$95 = \frac{Sc\ (45 - Sc)}{45\ (80 - Sc)}$$

Sc = 5% = wt % of solids in the centrate

The centrifuge used for phase separation is solid bowl conveyor centrifuge.

For 95% solid removal and conveyor centrifuge

$$\frac{Q}{T} = .0015\ \frac{cm}{minute} \qquad \text{(Ref. 1)}$$

Where Q = flow rate , $\frac{cc}{mt}$

T = theoretical capacity factor, Sq cm

and $T = 2\pi\, l\, \frac{\omega_1^2}{g}\left(3/4\ r_2^{\ 2} + 1/4\ r_1^{\ 2}\right)$

l = effective clarifying length of the centrifuge bowl, cm

r_2 = radius of the inside wall of the centrifuge bowl, cm

r_1 = radius of the liquid surface in the centrifuge bowl, cm

ω_1 = angular velocity of the centrifuge bowl, radians/sec.

g = acceleration of gravity, cm/sec^2

Based on the centrifuge manufacturer's information, the following assumptions are made

$$@\ r_2 = 9'' = 22.9 \text{ cm}$$

$$r_1 = 8.5'' = 21.6 \text{ cm}$$

$$\text{speed} = 2,400 \text{ r.p.m.}$$

$$T = \frac{Q}{.0015} = 32320 \frac{\text{cu.cm.}}{\text{mt}} \ \frac{1}{.0015} \frac{\text{mt}}{\text{cm}}$$

$$= 2.150 \times 10^7 \text{ cm}^2$$

$$= \frac{2 \times 3.14 \times 1 \times \left\{\frac{2,400}{60} \times 6.28\right\}^2 \left\{.75.(22.9^2) + .25.(21.6^2)\right\}}{980}$$

$$1 = 104 \text{ cm} \approx 41''$$

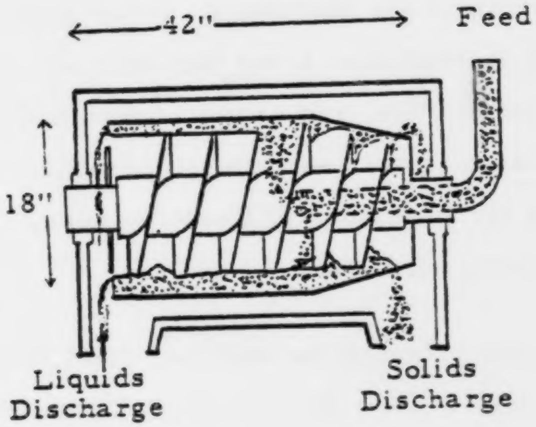
Centrifuge Design Summary

Centrifuge Size	
Length	42"
Diameter	18"
Operation, hr/day	24
Conveyor speed, r.p.m.	2,400
Capacity Factor, T, Sq cm	2.150×10^7
Influent characteristics	
Mass Flow, ------------lbs/hr	4,746
Solid concentration,	45
Centrate characteristics	
Mass Flow,	2,222
Solids concentration, %	5

Centrifuge Design Summary - continued

Concentrate characteristics

Mass Flow,	2,522
Solids concentration, %	80


42"
Feed
18"
Liquids Discharge
Solids Discharge

CALCINATION

$CaCO_3$ is present in the wet cake from the centrifuge, but its concentration is not known. It will be assumed that 3% of the total solid content is $CaCO_3$. The optimum residence time in the calciner for the decomposition of feed containing $CaCO_3$ has been found to be in the vicinity of 130 minutes. The same residence time will be taken for the present calciner. There might be other calcinable or decomposable matter present in the feed, but the type and concentration are not known, hence for the present calciner specification purpose only $CaCO_3$ will be considered.

The decomposition temperature of calcium carbonate is 825°C (1517°F) So the exit flue gas temperature will be close to 850°C and the temperature in the calciner at some point might reach around 1000°C. In the calciner a wet feed kiln will have three arbitrary zones. 1) Drying zone at feed end removes moisture 2) Heating zone where the charge is heated to the reaction temperature; i.e., the decomposition temperature for limestone 3) Reaction zone, the charge is burned, decomposed, reduced, oxidized, etc.

Amount of cake entering the calciner for 130 minutes (i.e., the residence time) = 130 x 42.14 = 5478.2 lbs. and the amount of different materials in the feed is

Solids	5478.2 x .8 =	4383	lbs.
Water	5478.2 x .197 =	1078	lbs.
Oil	5478.2 x .003 =	16	lbs.

The content of $CaCO_3$ in the feed stream is

3% of 4383 = 131.49 lbs.

1.31 lb. moles

$$CaCO_3 \longrightarrow CaO + CO_2$$

	$CaCO_3$	CaO	CO_2
lb moles	1.31	1.31	1.31
heat of formation	$(-5.2\times10^5 \frac{Btu}{lb\ mole})$	(-2.73×10^5)	(-1.693×10^5)

heat of decomposition of $CaCO_3$

$$= -1.6993\times10^5 - 2.73\times10^5 + 5.2\times10^5$$

$$= 10^5 \times 0.7707 \ \frac{Btu}{lb}\text{mole}$$

heat required to decompose

1.31 lb moles of $CaCO_3$ =

$$1.31\times10^5 \times .7707 = 1.0096\times10^5 \text{ Btu}$$

The calciner will be operated at atmospheric pressure. So the water present will be evaporated at 212°F and will be super heated to 1520°F

The total heat required for the evaporation of water =

Sp heat of water from 77 to 212°F + heat of vaporization at 212°F + Sp heat of water vapor from 212 to 1520°F.

a) Specific heat

$$= (212 - 77)\ ^{\circ}F \times 1078.30 \text{ lb} \times 1 \frac{Btu}{^{\circ}F\ lb}$$

$$= 1.4557\times10^5 \text{ Btu}$$

b) Latent heat

$$= \text{lb } 1078.30\times680 \frac{Btu}{lb} = 7.33\times10^5 \text{ Btu}$$

c) Sp heat

$$= (1520 - 212) \times 1078.30\times \frac{(.45 + .55)}{2} \frac{Btu}{lb\ ^{\circ}F}$$

$$= 7.052\times10^5 \text{ Btu}$$

Total heat absorbed = (1.4557 + 7.33 + 7.05) x 105

by water vapor = 15.8357×10^5

15.84×10^5 Btu/130 minutes

Total heat required

$15.84 \times 10^5 + .78 \times 10^5$

16.62×10^5 Btu/130 minutes

Thermal efficiency of a high temperature direct heat rotary kiln will range from 55 to 75%.

Assuming an efficiency of 60% the heat required from natural gas $= \frac{16.62 \times 10^5}{0.6}$

$= 27.7 \times 10^5$ Btu/130 minutes

Typical Natural Gas Analysis (based on the available N. Gas in Los Angeles, California)

Component	% by Volume
Methane	86.50
Ethane	8.00
Propane	1.90
Butanes	.30
Pentanes	.10
Hezanes	.10
CO_2	.50
N_2	2.60
Heating value, Btu/cu. ft.	1084
Specific gravity	.638

$$\text{Natural Gas Burned} = \frac{27.7\text{x}10^{5}\ \text{Btu}}{1.084\text{x}10^{3}\text{cu.ft.}}$$

$$= \frac{25.55\text{x}10^{2}\ \text{SCF}}{130\ \text{minutes}}$$

$$= 11.79\text{x}10^{2}\ \text{SCFH}$$

volume @ 77°F =

$$\frac{460 + 77}{460 + 32} \times 359 = 391.84\ \frac{\text{SCF}}{\text{Moles}}$$

$$\text{Natural Gas Burned} = \frac{11.79\text{x}10^{2}}{391.84} = 3.008\ \frac{\text{Moles}}{\text{hr}}$$

Composition of Total Natural Gas Burned

Component	Volume %	Moles/hr
CH_4	86.50	2.60
C_2H_6	8.00	0.24
C_3H_8	1.90	0.057
C_4H_{10}	.30	0.009
C_5H_{12}	.10	0.003
C_6H_{14}	.10	0.003
CO_2	.50	0.015
N_2	2.60	0.078

CALCINATION - continued

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2H_2O$$

$$C_2H_6 + 3\,1/2\,O_2 \longrightarrow 2\,CO_2 + 3H_2O$$

$$C_3H_8 + 5\,O_2 \longrightarrow 3\,CO_2 + 4H_2O$$

$$C_4H_{10} + 6\,1/2\,O_2 \longrightarrow 4\,CO_2 + 5H_2O$$

$$C_5H_{12} + 8\,O_2 \longrightarrow 5\,CO_2 + 6H_2O$$

$$C_6H_{14} + 9\,1/2\,O_2 \longrightarrow 6\,CO_2 + 7H_2O$$

Stoichiometric Balance

	Feed Mole/hr	O_2 Required Mole/hr	CO_2 Formed Mole/hr	H_2O Formed Mole/hr
From CH_4	2.60	5.20	2.60	5.20
From C_2H_6	0.24	0.84	0.48	0.72
From C_3H_8	0.057	0.285	0.17	0.228
From C_4H_{10}	0.009	0.058	0.036	0.045
From C_5H_{12}	0.003	0.024	0.015	0.018
From C_6H_{14}	0.003	0.028	0.018	0.021
CO_2	0.015	-	0.015	-
N_2	0.078	-	-	-
	3.005	6.435	3.334	6.232

Stoichiometric Balance - continued

Assuming an excess oxygen of 20% required

Total O_2 required $= 6.435 + .15 \times 6.435$

$= 7.400 \frac{\text{mole}}{\text{hr}}$

N_2 with air $= 7.400 \times \frac{79}{21} = 27.84 \frac{\text{moles}}{\text{hr}}$

Chemical Reactions

$CaCO_3$ $\longrightarrow$	CaO +	CO_2
1.31 lb moles	1.31 lb moles	1.31 lb moles
(131 lbs)	(73.36 lbs)	(57.64 lbs)

Ca O formed $= 1.31 \times 56 = 73.36$ lbs (solids)

$CO_2 = \frac{1.31 \times 44}{130} = \frac{57.64 \text{ lbs}}{130 \text{ minutes}}$ or $\frac{1.31 \text{ lb}}{130} \frac{\text{moles}}{\text{mts}}$

$= .60 \text{ lb} \frac{\text{moles}}{\text{hr}}$

Total CO_2 in the flue gases $= (3.334 + 0.60) = 3.93 \frac{\text{moles}}{\text{hr}}$

Flue Gas Composition Including Reaction CO_2 (wet basis)

	Mol/hr	Mol %	N.W.	lbs/hr	wt. %
O_2	.965	2.5	32	30.88	2.8
N_2	27.84	71.40	28	779.52	71.25
CO_2	3.93	10.1	44	172.92	15.8
H_2O	6.232	16.0	18	112.18	
Total	38.97	100		1095.5	100.00

Total H_2O in flue gases $= 6.232 \frac{\text{moles}}{\text{hr}}$

Partial pressure of $H_2O = \frac{6.232}{.965+27.84\_3.93+6.232} \times 14.7 = 2.35$ psia

Condensing Temperature =

Total feed to the calciner for 130 minutes period = 5478.2 lbs.

Assuming an average specific gravity of 1.1

$$\text{Then volume of feed} = \frac{1.1 \text{x} 5478.2}{63 \; \frac{\text{lbs}}{\text{ft}^3}}$$

$$= 95.65 \text{ ft}^3$$

Rotary kiln calciners usually operate with 10 to 15 percent of their volume filled with material (Perry & Chilton)

The approximate volume of the

$$\text{dryer} = \frac{100}{10} \text{ x } 9.554 = 956.5 \text{ cu. ft.}$$

In the case of lime kiln calciners, it has been shown that as the length to diameter ratio is increased from 10:1 to 30:1, its performance increases upto the optimum of 30:1 (Ref 2)

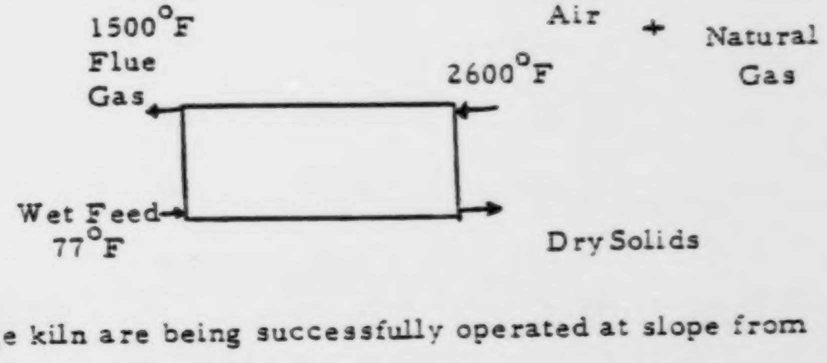
Assuming an optimum ratio of length: diameter as 14:1 in the present study,

then $\pi R^2 (28 R) = 956.5$ cu ft.

$R \approx 2.25$

Diameter = 4.5 feet

Length $= 28 R \approx 60$ feet



Lime sludge kiln are being successfully operated at slope from

$\frac{1/4''}{\text{ft}}$ to $\frac{1/2''}{\text{ft}}$

Assuming a slope of 3/8"/ft

The hold up time for rotary kiln calciners is given by

$t = 2.28 \; L/NDS$ (Ref. 3)

Where t = hold up time = 130 minutes

D = Actual diameter of the kiln (without refractory lining) = 4.5 feet

L = Length of the kiln = 60 feet

S = Slope = 3/8 in/ft.

N = Rotational speed, rpm

$$N = \frac{2.28\,L}{tDS} = \frac{2.28 \times 60}{130 \times 4.5 \times 3/8} = 7 \text{ rpm}$$

Total moles of flue gas leaving the calciner = 38.98 $\frac{\text{moles}}{\text{hr}}$

Actual cubic feet per hour (AC FH) of flue gas leaving the calciner

$$= \left\{ \frac{460 + 1500}{460 + 32} \right\} \times 38.98 \times 359$$

$$= 55747.73$$

ACFM = 929

Calciner Design Summary

Length of the calciner = 60 feet

Inside diameter of calciner = 4.5 feet

Refractory lining = 9"

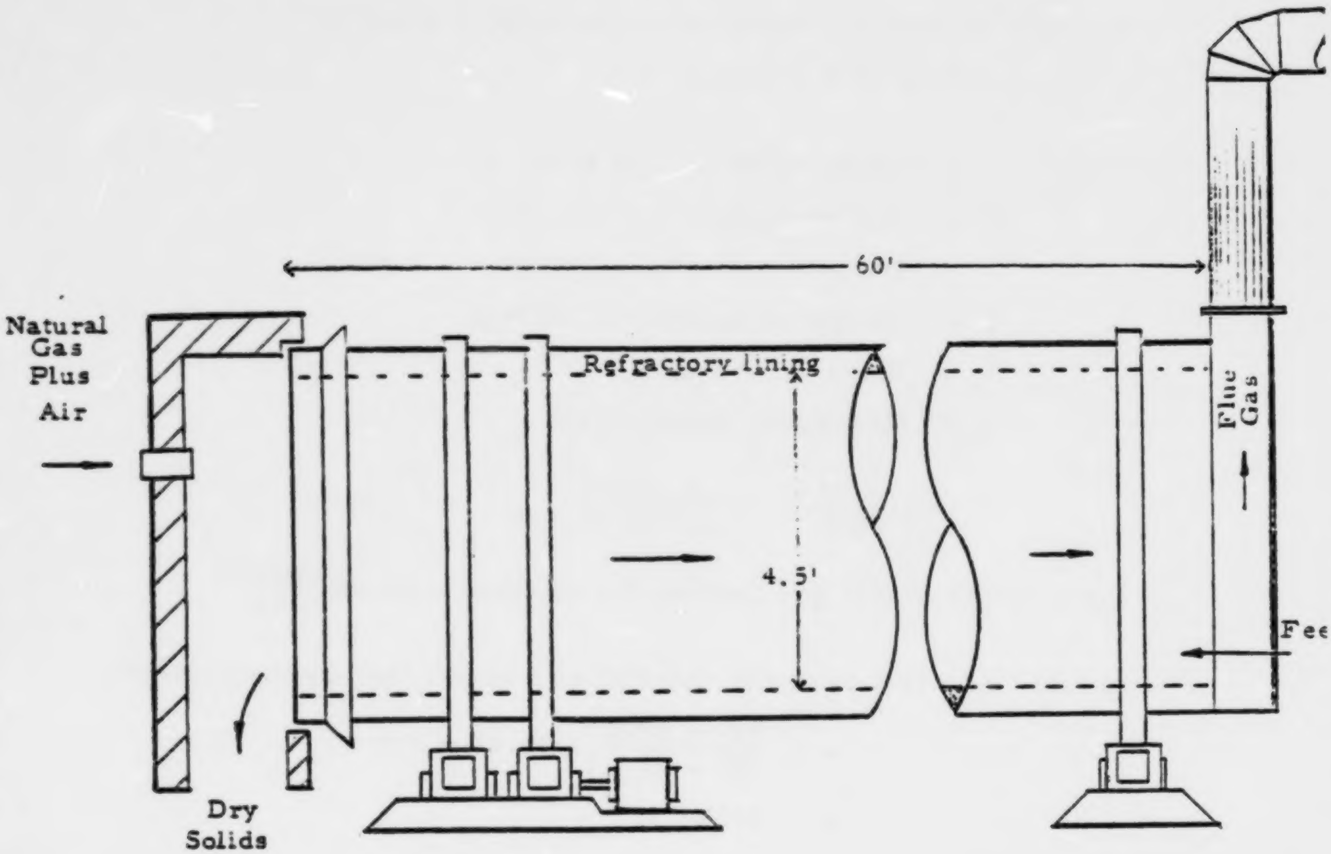
Rotational speed = .7 rpm

Slope = 3/8"/ft.

Residence time of material = 130 minutes

Amount of wet feed entering the calciner = 2523 lbs/hr

ACFM of flue gas leaving the calciner = 929



60'
Natural Gas Plus Air
Refractory lining
4.5'
Flue Gas
Fee
Dry Solids

Rotary Kiln Calciner

(4) Cyclone and Scrubber

ACFM of flue gas = 929

Assuming 2% of the solid leaving the calciner as particulates with the flue gas, then the amount = .02x2022.77 = 40.45 lbs/hr

$$\text{Density of flue gas (d)} = (1095.5 + 40.45)\ \text{lbs/hr} \times \frac{1}{55747.73}\ \frac{\text{hr}}{\text{ft}^3}$$

$$= .02\ \text{lbs/ft}^3$$

Viscosity of flue gas entering cyclone

Gas Component	wt %	Viscosity of Pure Gas Component, Centipoise	Viscosity Fraction, Centipoise
O_2	2.8	.05	.028x.05 = .0014
H_2	71.2	.045	= .032
CO_2	15.8	.052	= .008
H_2O	10.2	.04	= .004
	Viscosity of Flue Gas		.045

Based on manufacturer's information (Stansteel Corp.-Los Angeles, CA) the cyclone best suited to the conditions has the following dimensions.

Maximum diameter or diameter of the cylindrical section = 40 inches

Total length of the cyclone = 5.5 feet

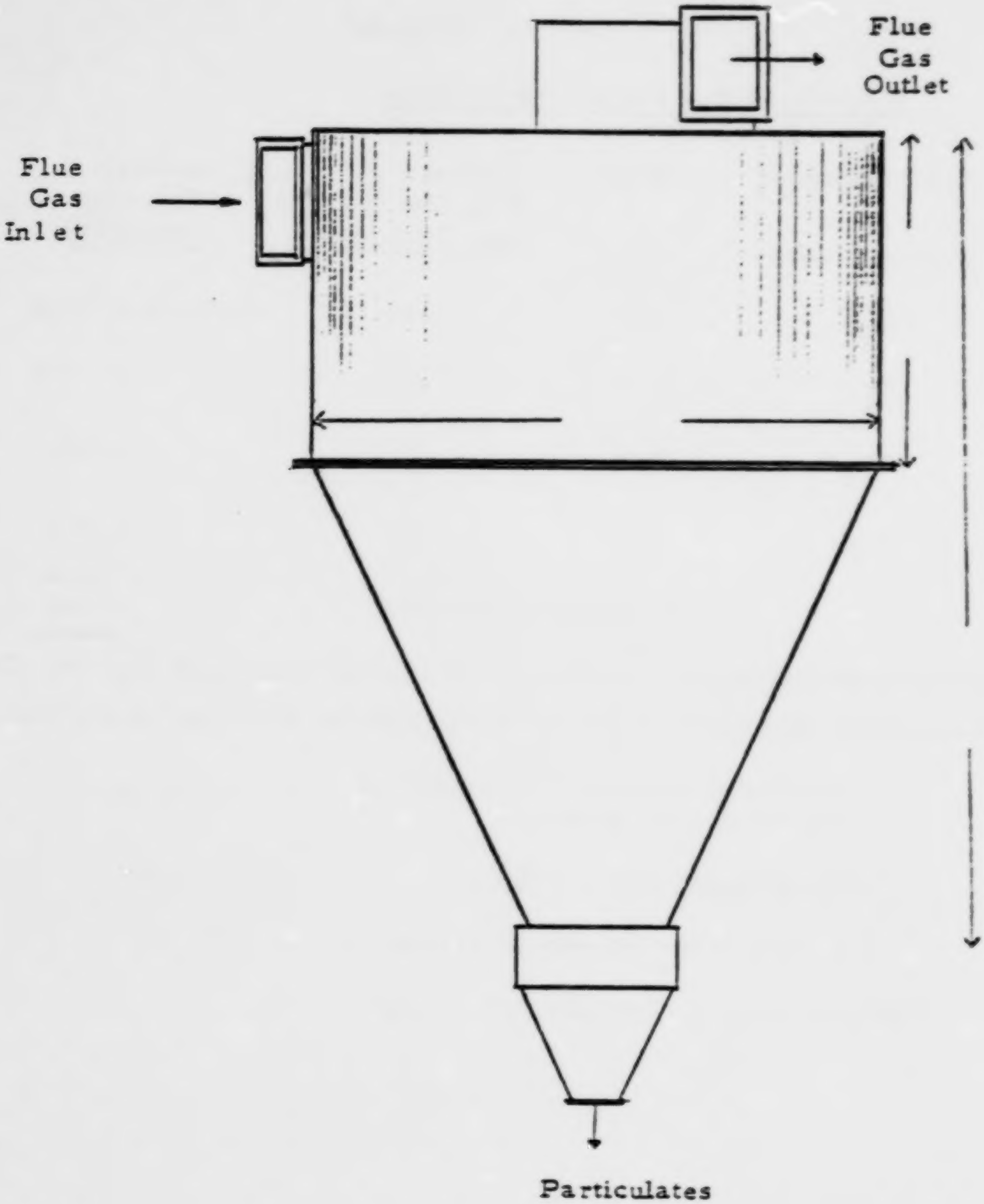
Length of the cylindrical section = 2 feet

Pressure drop = 2 inches water guage

(4) Cyclone and Scrubber - continued

It is assumed that 70% of the particulates (comprised of coarse diameter) are settled in the cyclone.

The amount of particulate that settle in the cyclone = 17x40.45
= 28.3 lbs/hr


Flue
Gas
Outlet
Flue
Gas
Inlet
Particulates

(4) Cyclone and Scrubber - continued

Based again on the same manufacturer's (Stansteel Corp. Los Angeles, CA.) information, the high efficiency venteri - impacter type wet scrubber best suited to the conditions has the following dimensions.

Diameter of scrubber = 35 inches

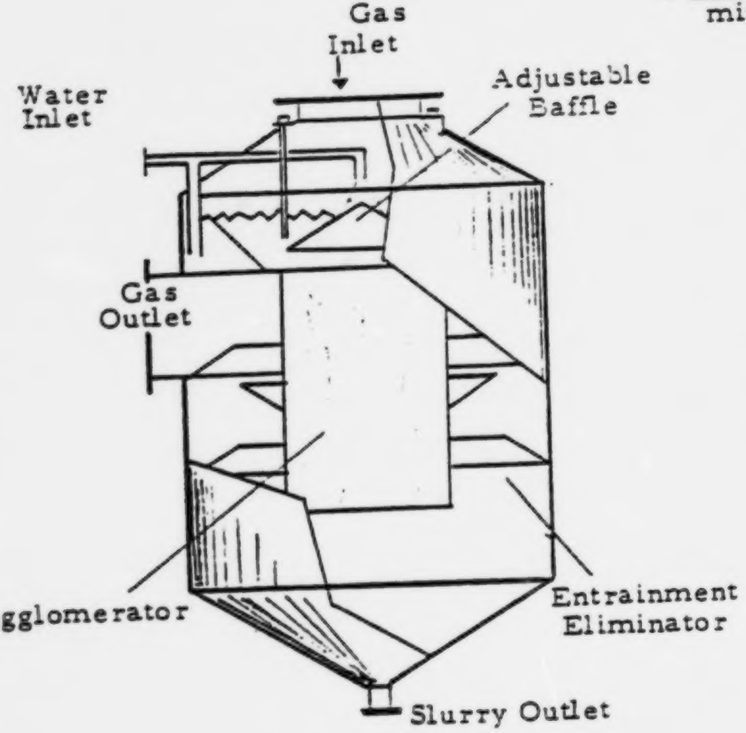
Length of scrubber = 36 inches

Pressure drop = 12 inches water guage

It is assumed that 99.5% of the remaining 30% of the fine particulates gets separated.

Amount of scrubbing liquid (centrate) required = $\frac{\text{8 gallons}}{\text{1000 cu.ft. off.gas}}$

$= \frac{\text{7 gallons}}{\text{minutes}}$


Gas Inlet
Water Inlet
Adjustable Baffle
Gas Outlet
Agglomerator
Entrainment Eliminator
Slurry Outlet

The clean exit gas from the scrubber goes through a stack 24 inches in diameter and 30 feet high before being vented to the atmosphere.

APPENDIX H

DETAILS OF INCINERATION SYSTEM

Included is the heat balance calculations and equipment sizing for a fluidized bed incinerator to handle candidate waste streams from a 200,000 BPSD refinery.

APPENDIX 10.8

DETAILS OF INCINERATION SYSTEM
FLUIDIZED BED INCINERATOR
HYPOTHETICAL 200,000 BPSD REFINERY

WASTE QUANTITIES

A. Continuous Waste Streams

Constituent	Quantity (lbs/day)
Oil	23,200
Water	141,300
Solids	74,200
	238,700

HEAT INPUT

A. Oil - $23,200 \frac{\text{lbs}}{\text{day}} \times 18,000 \frac{\text{Btu}}{\text{lb}} = 4.18 \times 10^8 \frac{\text{Btu}}{\text{day}}$

B. Coke - $10 \frac{\text{lbs}}{\text{day}} \times 8.47 \frac{\text{Btu}}{\text{lb}} = 84.8 \frac{\text{Btu}}{\text{day}} \Longleftarrow$ negligible

HEAT CONSUMPTION

A. Water (assume feed at 70°F, flue gas at 500°F)

1. From 70°F to 212°F

$$141,300 \frac{\text{lbs}}{\text{day}} \times \frac{\text{Btu}}{\text{lb F°}} \times 142\text{F°} = 2.01 \times 10^7 \frac{\text{Btu}}{\text{day}}$$

$$= 0.20 \times 10^8 \frac{\text{Btu}}{\text{day}}$$

2. From 212°F (L) to 212°F (v)

$$141,300 \frac{\text{lbs}}{\text{day}} \times 972 \frac{\text{Btu}}{\text{lb}} = 1.37 \times 10^8 \frac{\text{Btu}}{\text{day}}$$

HEAT CONSUMPTION - continued

A. continued

3. From 212°F (v) to 500°F

$$141,300 \ \frac{\text{lbs}}{\text{day}} \times 0.45 \ \frac{\text{Btu}}{\text{lb F°}} \times 288\text{F°} = 1.83 \times 10^{7} \ \frac{\text{Btu}}{\text{day}}$$

$$= 0.18 \times 10^{8} \ \frac{\text{Btu}}{\text{day}}$$

B. Solids (assume as sand (SiO_2)

Solids will be heated to operating temperature of the incinerator bed - 1200°F

$$74,200 \ \frac{\text{lbs}}{\text{day}} \times 0.19 \ \frac{\text{Btu}}{\text{lbF°}} \times (1200 - 70) \text{ F°} = 1.59 \times 10^{7} \ \frac{\text{Btu}}{\text{Day}}$$

$$0.16 \times 10^{8} \ \frac{\text{Btu}}{\text{Day}}$$

EXCESS HEAT

In - $4.18 \times 10^{8} \ \frac{\text{Btu}}{\text{day}}$

Out - 0.20×10^{8} Btu/day
1.37×10^{8}
0.18×10^{8}
$\underline{0.16} \times 10^{8}$
1.91×10^{8} Btu/day

Excess $(4.18 - 1.91) \times 10^{8}$ Btu/day
2.27×10^{8} Btu/day

Assumptions -
1. Heat loss from incinerator negligible
2. Excess heat to be carried from incinerator by combustion gasses
3. Space velocity in incinerator bed to be 3 ft/sec
4. Bed diameter sized to give sufficient area so that volume of air involved will carry off all excess heat

QUANTITY OF AIR REQUIRED

Air enters at 70°F $\Delta T = 430°F$
Flue gas at 500°F

$$\frac{2.27 \times 10^8 \text{ Btu/day}}{7.38 \text{ Btu/mole F°}} \times \frac{1}{430°F} = 7.15 \times 10^4 \frac{\text{mole}}{\text{day}} \text{ (air)}$$

$$7.15 \times 10^4 \frac{\text{moles}}{\text{day}} \times \frac{\text{day}}{24 \times 60 \text{ sec}} = 49.65 \frac{\text{moles}}{\text{min}}$$

@ 70°F, 1 atm - 1 lb mole air occupies 386.9 cu ft

$$49.65 \frac{\text{moles}}{\text{min}} \times 386.9 \frac{\text{cu ft}}{\text{moles}} = 19{,}209.6 \text{ cfm}$$

Bed space velocity - $\frac{3 \text{ ft}}{\text{sec}} = 180 \frac{\text{ft}}{\text{min}}$

$$\text{Area required} = \frac{\text{volume flow}}{\text{velocity}}$$

$$A = \frac{19{,}209.6 \text{ cfm}}{180 \text{ ft/min}} = 106.7 \text{ sq ft}$$

$$\text{Bed diameter} = 2\sqrt{\frac{A}{\pi}} = 2\sqrt{\frac{106.7}{\pi}} = 11.65 \text{ ft}$$

Assume safety factor of 25% in bed design

11.65 ft x 1.25 = 14.57 ft

Say $\Longrightarrow$ 14-1/2 ft

EQUIPMENT SIZE
FLUIDIZED BED INCINERATOR
200,000 BPSD Refinery

STORAGE VESSELS (Assume 30 day capacity)

Quantity 238,640 $\frac{\text{lbs}}{\text{day}}$ x 30 days = 7,159,200 lbs

Assume waste has sig. of 1.0

$$7,159,200 \text{ lbs} \times \frac{\text{gal}}{8.34 \text{ lbs}} \times \frac{\text{Bbl}}{42 \text{ gal}} = 20,438 \text{ Bbls}$$

Refinery will most likely utilize two (2) - 10,000 Bbl tanks

FLUIDIZING AIR BLOWER

From Page 3 - "Heat Balance"

19,209.6 cfm required

Assume safety factor of 100%
(Note: high space velocities may occasionally be required to maintain bed fluidity.)

19,209.6 x 2 = 38,420 acfm @ 70°F, 1 atm

INCINERATOR BED

From Page 4 "Heat Balance" $\Longrightarrow$ 14-1/2 ft diameter

CYCLONE

Assume Fuel : $CH_{1.5}$ (23,200 lbs/day = 16.11 lbs/min)
Air 21% O_2
79% N_2 (lb moles/min)

Component	Burned (lbs/min)	lb moles/min	lb /moles O_2	Combustion Products CO_2	H_2O
C	14.32	1.19	1.19	1.19	
H	1.79	1.79	0.45		0.90
			1.64		

REACTIONS

$C + O_2 \quad CO_2$
$2H + 1/2\ O_2 \quad H_2O$

AIR - 49.65 $\frac{\text{moles}}{\text{min.}}$ 49.65 x 0.21 = 10.43 moles/min (O_2)
x 0.79 = 39.22 moles/min (N_2)

1.64 lb. moles of O_2 consumed in combustion process.
2.09 lb. moles of combustion products

Flue Gas Quantity = 39.22 + (10.43 - 1.64) + 2.09 lb moles/min
= 50.10 lb moles/min.

At 70°F, 1 atm - lb mole gas occupies 286.9 cu. ft.
Assume gas at 500°F in cyclone

$$50.10\ \frac{\text{lb moles}}{\text{min.}} \times \frac{386.9\ \text{cu. ft.}}{\text{lb. mole}} \times \frac{(460 + 500)}{(460 + 70\ )} = 35,100\ \text{acfm @ } 500°\text{F}$$

Assume safety factor of 100% (same as air blower)

Cyclone design capacity 70,200 acfm @ 500°F

WET SCRUBBER

Assume: same air flow as cyclone temperature at 400°F

$$70,200\ \text{cfm} \times \frac{(460 + 400)}{(460 + 500)} = 62,900\ \text{acfm @}400°\text{F}$$

SOLID REMOVAL SYSTEM

Assume: all solids require removal from the bed safety factor of 25%

$$74,200\ \frac{\text{lbs}}{\text{day}} \times 1.25 = 92,750\ \frac{\text{lbs}}{\text{day}}$$

WASTE FEED SYSTEM

Assume at 125% system capacity

$$238,640\ \frac{\text{lbs}}{\text{day}} \times \frac{\text{gal}}{8.34\ \text{lbs}} \times \frac{\text{day}}{24 \times 60\ \text{min}} \times 1.25 = 24.8\ \text{gpm}$$

Say $\Longrightarrow$ 25 gpm

APPENDIX I

LIST OF INDUSTRY CONTACTS

Included is a "Profile of Major U.S. Refiners" and the person/persons to be contacted to get additional information. The American Petroleum Institute requested that they do the contacting for JEC. The industries they contacted are included in Appendix 10.10 (deleted). This is so because API selected the candidate refiners on their own.

AMOCO OIL CO.
200 E. Randolph
Chicago, Ill. 60601
(312) 856-5111

Capacity 1,117,000 Bbl/Day
10 Refineries

RESEARCH & DEVELOPMENT DEPT
Chicago, Ill. 60601
(312) 856-5910
T. B. Tom - V. P. R & D
T. O. Wagner - Coord. Prod. & Proc. Dev.

RESEARCH & DEVELOPMENT DEPT.
Box 431
Whiting, Ind. 46394
R. A. Steel - Lab Manager
K. W. McHenry - Dir. Proc. & Anal. Res.

RESEARCH & DEVELOPMENT DEPT.
Naperville, Ill. 60540
(312) 420-5111

ENGINEERING DEPT.
Chicago
(312) 856-7781
R. S. Holcomb - Man. Engr.

REFINING DEPT.
Chicago
(312) 856-5453
W. T. Herget - Gen. Man. Refining

REFINERIES

Baltimore Md. (301) 355-2105	15,000 Bbl/Day
Casper Wy. (307) 234-1220	43,000 Bbl/Day
Manden N. D. (701) 663-7420	49,000 Bbl/Day

REFINERIES - continued

Salt Lake City (801) 364-4104	39,000 Bbl/Day
Savannah, Ga. (912) 964-6282	13,000 Bbl/Day
Sugar Creek, Mo. (816) 252-4800	107,000 Bbl/Day
Texas City, Tex. (713) 945-2311	333,000 Bbl/Day
Whiting, Ind. (219) 659-2700	360,000 Bbl/Day
Wood River, Ill. (618) 254-7351	105,000 Bbl/Day
Yorktown, Va. (804) 898-5120	53,000 Bbl/Day

ASHLAND OIL, INC.
1401 Winchester Avenue
Ashland, Ky. 41101
(606) 329-3333

Capacity 319,000 Bbl/Day
6 Refineries

REFINERIES

Catlesburg, Ky. (606) 329-3333	135,000 Bbl/Day
Buffalo, N. Y. (716) 877-7177	68,000 Bbl/Day
Canton, Ohio (216) 477-4561	64,000 Bbl/Day
Findlay, Ohio (419) 422-4511	20,000 Bbl/Day
Louisville Refining Co. Louisville, Ky. (502) 583-4861	25,000 Bbl/Day
Valvoline Oil Co. Freedom, Pa. (412) 774-2020	7,000 Bbl/Day

ATLANTIC RICHFIELD CO.
515 S. Flower
Los Angeles, California 90071
(213) 486-3511

Capacity 814,000 Bbl/Day
6 Refineries

MANUFACTURING, RESEARCH & ENGR.
Los Angeles, Ca.
(213) 486-3511
T. V. Griffiths - Man. Manufacturing

TECHNICAL SERVICE CENTER
400 E. Sibley Blvd.
Harvey, Ill. 60426
N. J. Schlesser - Man.
A. G. Plys - Man. Manf., Tech, & Eval.
G. F. Masologoites - Man. Manf. Res. & Dev.

REFINERIES

Point Breeze Philadelphia, Pa. (215) 465-2345	185,000 Bbl/Day
Houston, Tx. (713) 477-6811	213,000 Bbl/Day
Cherry Point Ferndale, Wash. (206) 384-1500	96,000 Bbl/Day
Watson Carson, Ca. (213) 834-2521	181,000 Bbl/Day
East Chicago, Ind. (219) 397-0942	126,000 Bbl/Day
North Slope, Alaska	13,000 Bbl/Day

CITIES SERVICE OIL CO.
Cities Service Bldg.
7th & Boulder
Tulsa, Okla. 74102
(918) 560-2211

Capacity 268,000 Bbl/Day
1 Refinery

LAKE CHARLES REFINERY — 268,000 Bbl/Day
Box 1562
Lake Charles, La. 70601
(318) 491-6011
J. S. Brendler - Gen. Man.
R. V. Forest - Man. Public Relations
L. M. Nollkamper - Sup. Proc. Engr.

CONTINENTAL OIL CO.
Box 2197
Houston, Tx. 77001
(713) 627-4011

Capacity 373,500 Bbl/Day
7 Refineries

REFINING DEPARTMENT
Box 2197
Houston, Tex.
(713) 627-4642
W. L. Walker - V. P.
J. T. Zeien - Man. Oper.
W. R. Stroud - Man. Ref. Dev. & Econ.

TECHNICAL SERVICES DIVISION
Box 1267
Ponca City, Okla. 74601
K. C. Hunt - Dir. Laboratory

REFINERIES

Ponca City, Okla. (405) 762-3456	126,000 Bbl/Day
Westlake, La. (318) 436-9651	83,000 Bbl/Day
Commerce City, Co. (303) 534-2100	32,500 Bbl/Day
Billings, Mont. (406) 252-3841	52,500 Bbl/Day
Wrenshall, Minn. (218) 384-4245	23,500 Bbl/Day

Douglas Oil Co. of
California
Box 60205
Los Angeles, CA 90060

Paramount Refinery	46,000 Bbl/Day
Santa Maria Refinery	10,000 Bbl/Day

EXXON CO. U. S. A.
Refining Department
Box 2180
Houston, Tex. 77001
F. D. Dennstedt - V. P.

Capacity 1,243,000 Bbl/Day
5 Refineries

ESSO RESEARCH & ENGINEER CO.
Box 111
Linden, New Jersey 07036
N. V. Hakal - President

REFINERIES

Baton Rouge, La. (504) 359-7711	455,000 Bbl/Day
Baytown, Tex. (713) 427-5711	390,000 Bbl/Day
Bayway Refinery Linden, N. J. (201) 474-0100	265,000 Bbl/Day
Benica, Ca. (707) 745-3450	88,000 Bbl/Day
Billings, Mont. (406) 252-3811	45,000 Bbl/Day

GULF OIL CORP.
Gulf Bldg.
Pittsburg, Pa. 15230
(412) 391-2400

Capacity 866,000 Bbl/Day
8 Refineries

GULF RESEARCH & DEVELOPMENT CO.
Box 2038
Pittsburgh, Pa. 15230
T. R. Hopkins - Pres.

REFINERIES

Alliance Refinery Belle Chasse, La. (504) 656-7711	180,000 Bbl/Day
Cleves Refinery Cincinnati, Ohio (513) 941-3400	42,000 Bbl/Day
Philadelphia, Pa. (215) 465-3100	174,000 Bbl/Day
Por Arthur, Tex. (713) 983-3301	312,000 Bbl/Day
Santa Fe Springs, Ca. (213) 921-3581	52,000 Bbl/Day
Toledo, Ohio (419) 729-3871	50,000 Bbl/Day
Venice, La. (504) 534-7452	29,000 Bbl/Day
Hercules, Ca. (413) 758-4840	27,000 Bbl/Day

MARATHON OIL CO.
539 S. Main St.
Findlay, Ohio 45840
(419) 422-2121

Capacity 324,000
3 Refineries

REFINING
Findlay
C. H. Barre - V. P. Refining
W. T. Maddock - Major Proj. & Engr. Man.

REFINERIES

Robinson, Ill. (618) 544-2121	195,000 Bbl/Day
Detroit, Mich. (313) 843-9100	65,000 Bbl/Day
Texas City, Tex. (713) 945-2331	64,000 Bbl/Day

MOBIL OIL CORP.
150 E. 42nd St.
New York, N. Y. 10017
(213) 883-4242

Capacity 887,000 Bbl/Day
7 Refineries

REFINERIES

Torrance, Ca. (213) 328-2550	124,000 Bbl/Day
Ferndale, Wash. (206) 384-1011	72,000 Bbl/Day
Buffalo, N. Y. (716) 825-8500	43,000 Bbl/Day
Paulsboro, N. J. (609) 423-1040	98,000 Bbl/Day
Augusta, Kansas (316) 775-6371	50,000 Bbl/Day
Beaumont, Tex. (713) 833-9411	325,000 Bbl/Day
Joliet, Ill. (815) 423-5571	175,000 Bbl/Day

PHILLIPS PETROLEUM CO.
Bartlesville, Okla. 74004
(918) 661-6600

Capacity 408,000 Bbl/Day
6 Refineries

RESEARCH & DEVELOPMENT DEPT.
Bartlesville, Okla. 74004
(918) 336-6600
P. M. Arnold - V. P.

REFINERIES

Woods Cross, Utah (801) 295-2311	23,000 Bbl/Day
Great Falls, Mont. (406) 453-4371	6,000 Bbl/Day
Borger, Tex. (806) 273-2831	99,000 Bbl/Day
Kansas City, Ks. (913) 342-7108	85,000 Bbl/Day
Sweeny, Tex. (713) 548-3333	85,000 Bbl/Day
Martinez, Ca. (415) 228-1220	110,000 Bbl/Day

SHELL OIL CO.
One Shell Plaza
Box 2463
Houston, Tex. 77001
(713) 220-6161

Capacity 1,154,000 Bbl/Day
8 Refineries

MANUFACTURING & MTM RESEARCH
Houston, Tex.
J. W. Sheehan - V. P.
G. Holzman - Gen. Man. Refining

SHELL DEVELOPMENT CO.
Box 3011
Modesto, Ca. 95353
R. W. Martin - Man. Biol. Sciences Research Center

REFINERIES

Wood River, Ill. (618) 254-7371	283,000 Bbl/Day
Houston, Tex. (713) 479-2311	294,000 Bbl/Day
Martinez, Ca.	100,000 Bbl/Day
Wilmington, Ca. (213) 835-5611	96,000 Bbl/Day
Norco, La. (504) 764-7511	240,000 Bbl/Day
Anacortes, Wash.	91,000 Bbl/Day
Gallup, N. M. (505) 722-3833	18,000 Bbl/Day
Odessa, Tex. (915) 337-5321	32,000 Bbl/Day

STANDARD OIL CO. OF CAL. Socal Total Capacity 1,020,000 Bbl/Day
225 Bush St. (Including Subsidaries)
San Francisco, Ca. 94104 11 Refineries
(415) 894-7700

REFINERIES

Richmond, Ca. (415) 232-1514	190,000 Bbl/Day
El Segundo, Ca. (213) 322-3450	230,000 Bbl/Day
Bakersfield, Ca. (805) 393-1312	26,000 Bbl/Day
Barbers Point, Haw. (808) 682-5711	40,000 Bbl/Day
Kenai, Alaska (907) 776-8161	22,000 Bbl/Day
Standard Oil (Ca.)	508,000 Bbl/Day

CHEVRON OIL CO. (Socal Subsidiary)
(Eastern Division) 888,000 Bbl/Day
1200 State St.
Perth Amboy, N. J. 08861

CHEVRON OIL CO.
(Western Division)
Box 599
Denver, Col. 80201
(303) 292-1400

REFINERIES

El Paso Tex. (915) 772-1411	71,000 Bbl/Day
Salt Lake City (801) 322-1511	45,000 Bbl/Day

STANDARD OIL CO. (Kentucky)
Chevron Oil Co. (Southern Division)
Stark Bldg.
Louisville, Ky. 40201

REFINERY

Pascagoula, Miss. (601) 762-8822	280,000 Bbl/Day
CHEVRON TOTAL	484,000 Bbl/Day

CHEVRON ASPHALT CO. (Subsidiary of Socal)
555 Market Square
San Francisco, Calif. 94105
(415) 894-7800

REFINERIES

Baltimore, Md. (301) 355-7800	14,000 Bbl/Day
Portland, Ore. (503) 222-4256	14,000 Bbl/Day
Chevron Asphalt	28,000 Bbl/Day

STANDARD OIL CO. (OHIO)
Midland Bldg.
Cleveland, Ohio 44115
(216) 575-4141

Capacity 431,000 Bbl/Day
3 Refineries

Note: Sohio has purchased interests of British Petroleum in the United States.

REFINERIES

Lima, Ohio (419) 233-6010	168,000 Bbl/Day
Toledo, Ohio (419) 248-1461	120,000 Bbl/Day
B. P. Oil Co. Marcus Hook, Pa. (215) 494-3600	143,000 Bbl/Day

SUN OIL CO.
240 Radnor Chester Rd.
St. Davids, Pa. 19087
(215) 985-1600

Capacity 484,000 Bbl/Day
4 Refineries

REFINERIES

Marcus Hook, Pa. (215) 485-1121	165,000 Bbl/Day
Toledo, Ohio (419) 691-3561	125,000 Bbl/Day
Tulsa, Okla. (918) 583-4300	89,000 Bbl/Day
Duncan, Okla. (405) 255-4440	48,000 Bbl/Day
Suntide Refining Co. Box 260B Corpus Christi, Tex. 78403 (512) 241-4811	57,000 Bbl/Day

TEXACO, INC.
135 E. 42nd St.
New York, N. Y. 10017
(212) 953-6000

Capacity 1,098,000
12 Refineries

REFINING DEPARTMENT - U. S.
1111 Rush Ave.
Houston, Tex. 77002
(713) 224-9811

REFINERIES

Port Arthur, Tex. (713) 982-5711	406,000 Bbl/Day
W. Tulsa, Okla. (918) 743-5311	50,000 Bbl/Day
Lockport, Ill. (815) 838-0770	72,000 Bbl/Day
Lawerenceville, Ill. (618) 943-3381	84,000 Bbl/Day
Westville, N. J. (609) 845-8000	88,000 Bbl/Day
Amarillo, Tex. (806) 374-4691	20,000 Bbl/Day
El Paso, Tex. (915) 772-1433	17,000 Bbl/Day
Casper, Wy. (307) 234-5377	21,000 Bbl/Day
Wilmington, Ca. (213) 835-8261	75,000 Bbl/Day
Port Neches, Tex. (713) 722-4331	47,000 Bbl/Day
Anacortes, Wash. (206) 293-2131	78,000 Bbl/Day
Convent, La. (504) 562-3541	140,000 Bbl/Day

UNION OIL CO.
Union Oil Ctr.
Los Angeles, Calif. 90017
(213) 486-7600

Capacity 489,000 Bbl/Day
4 Refineries

UNION 76 DIVISION
200 E. Golf Rd.
Palatine, Ill.
(312) 529-7700
R. N. Creek - V. P.
J. M. Hopkins - V. P. Refining

RESEARCH DEPARTMENT
Brea, Ca. 92621
W. E. Bradley - V. P.
H. C. Huffman - Ass. Director Refining & Products Research

REFINERIES

Chicao, Ill. (312) 257-7761	150,000 Bbl/Day
Beaumont, Tex. (713) 722-3441	120,000 Bbl/Day
Los Angeles, Ca. (213) 854-3421	108,000 Bbl/Day
San Francisco, Ca. (415) 799-4411	111,000 Bbl/Day

(4) Cyclone and Scrubber

ACFM of flue gas = 929

Assuming 2% of the solid leaving the calciner as particulates with the flue gas, then the amount = .02x2022.77 = 40.45 lbs/hr

$$\text{Density of flue gas (d)} = (1095.5 + 40.45)\ \text{lbs/hr} \times \frac{1}{55747.73}\ \frac{\text{hr}}{\text{ft}^3}$$

$$= .02\ \text{lbs/ft}^3$$

Viscosity of flue gas entering cyclone

Gas Component	wt %	Viscosity of Pure Gas Component, Centipoise	Viscosity Fraction, Centipoise
O_2	2.8	.05	.028x.05 = .0014
H_2	71.2	.045	= .032
CO_2	15.8	.052	= .008
H_2O	10.2	.04	= .004
		Viscosity of Flue Gas	.045

Based on manufacturer's information (Stansteel Corp.-Los Angeles, CA) the cyclone best suited to the conditions has the following dimensions.

Maximum diameter or diameter of the cylindrical section = 40 inches

Total length of the cyclone = 5.5 feet

Length of the cylindrical section = 2 feet

Pressure drop = 2 inches water guage

APPENDIX J

DATA FOR SELECTION OF A TYPICAL REFINERY

The enclosed table shows the distribution of refineries Types I through IV for the various states and the national total. This data was utilized in Section 2. 3 for selection of a typical refinery.

PROCESSING PROFILE OF MAJOR U. S. REFINERS

	No. Ref.	Crude Capacity (BPCD)	% Total U.S.	Additional Cap. Under Const. (BPCD)	Total of Present & Planned Cap. (BPCD)	% Total U.S.
Exxon	5	1,243,000	8.2	274,000	1,517,000	9.2
Shell	8	1,154,000	7.6	0	1,154,000	7.0
Amoco	10	1,117,000	7.4	0	1,117,000	6.8
Texaco	12	1,098,000	7.3	0	1,098,000	6.7
Standard (Cal)	11	1,020,000	6.8	430,000	1,450,000	8.8
Mobil	7	887,000	5.9	0	887,000	5.4
Gulf	8	866,000	5.7	51,000	917,000	5.6
Arco	5	814,000	5.4	6,000	820,000	5.0
Union	4	489,000	3.2	0	489,000	3.0
Sun	5	484,000	3.2	0	484,000	2.9
Sohio/BP	3	431,000	2.8	0	431,000	2.6
Phillips	6	408,000	2.7	0	408,000	2.5
Continental	7	374,000	2.5	0	374,000	2.3
Marathon	3	324,000	2.1	0	324,000	2.0
Ashland	6	319,000	2.1	0	319,000	1.9
Cities	1	268,000	1.8	0	268,000	1.6
	101	11,296,000	74.9	761,000	12,057,000	73.2
Others	155	3,792,000	25.2	625,000*	4,417,000	26.8
Total U. S.	256	15,088,000	100.0	1,386,000	16,474,000	100.0

BPCD - Barrels per Calender Day

* - includes 3 new refineries

(1) Oil & Gas Journal, March 29, 1976
(2) Oil & Gas Journal, April 26, 1976

APPENDIX K

PROCESSES NOT UNDER CONSIDERATION

PROCESSES NOT UNDER CONSIDERATION

CARBON ADSORPTION

Carbon adsorption is applicable to liquid waste streams for removal of: (1) toxic organic chemicals; (2) inorganics from aqueous waste streams; and (3) reduction of BOD, COD and related parameters of secondary treatment. Suspended solids should be less than 50 ppm to prevent clogging of the adsorption bed. All of the waste streams under consideration contain greater than 50 ppm suspended solids. If a low SS effluent were generated by application of another treatment process, the water would be returned to the headworks (usually an API separator) of the refinery's wastewater treatment system. Carbon adsorption would typically be used on the effluent of the biosystem prior to final discharge.

RESIN ADSORPTION

Resin adsorption is used to extract dissolved organic solutes from aqueous wastes. Any waste streams containing significant amounts of dissolved organics will also contain significant quantities of oil. Treatment schemes for removal of the oil phase will generally also remove dissolved organics. In addition, resin adsorption is similar to carbon adsorption in that SS must be below 50 ppm. Relatively little information is available on the few systems that are currently in operation.

BIOLOGICAL TREATMENT

(As a group)

Biological treatment methods are intended to decompose organics by biological activity. For the removal and recovery of oil an additional process or step would have to be incorporated. Removal of oil from the waste streams for recovery purposes would have all waste streams except waste bio-sludge lacking in organics, removing the necessity for bio-treatment. Waste bio-sludge is sufficiently high in solids that only two processes - composting and anaerobic digestion - are feasible. Metals if present in the waste stream, will inhibit growth of different biological species after recovery.

CATALYSIS	Catalysis is not a process by itself, but does modify an existing process. A catalyst is an agent which speeds up the reaction mechanism and is chemically unchanged at the end of the reaction. Catalysis would not normally be acceptable to sludges, tars or solids without preliminary treatment to bring the material into a more acceptable form. The oil and solids in the waste stream has to be removed before catalysis is applicable for detoxification of hazardous components in the water phase.
CHLORINOLYSIS	The reaction of chlorine with chlorinated hydrocarbons in the waste stream to form carbon tetrachloride is known as chlorinolysis. None of the waste streams under consideration contain significant amounts of chlorinated hydrocarbons.
DIALYSIS	Dialysis is a membrane separation process for separating solutes of differing molecular weights. Unfortunately use of this process results in product streams both of which are more dilute than the original. It is useful only if the recovery value of the material being separated is high. Commercial application of dialysis for waste treatment is sparse.
ELECTROLYSIS	Electrolysis is an oxidation or reduction reaction which occurs at an electrode immersed in a liquid. While some potential exists for removal of metals from water, there is limited applicability due to the low potential at which water electrolyzes. In addition, energy requirements are high and environmental problems exist due to the potential generation of hazardous gases.
ELECTRODIALYSIS	Electrodialysis is the separation of an aqueous solution into two streams: a stream more concentrated in the electrolyte (enriched stream) and a dilute stream (depleted stream). Application requires removal of suspended solids - in the case of a petroleum refinery, and the water would then be returned to the refineries' waste water treatment system. There is lack of practical experience on a commercial scale for waste treatment.

ELECTROPHORESIS	Electrophoresis is the transport of electrically charged particles under an electric current. The particles are not allowed to reach the electrode so oxidation-reduction reactions do not occur. As in electrolysis, the reactions possible are limited by the low potential at which water electrolyzes. Even the suspended particles have to have a net charge for the applicability of the process. It has limited commercial application.
EVAPORATION	The objective of the evaporation is the concentration of a solution consisting of a non volatile solute and a volatile solvent. Oil has to be removed or recovered before using this process. Even after the removal of oil, the energy costs for evaporation of water will be quite high and water vapor will have to be further treated for hazardous components that might vaporize with water or else will create an environmental air pollution problem.
FLOTATION	Flotation is the removal of solids or oils from aqueous waste streams by releasing air into the waste stream. Fine solids and imulsified oil will attach themselves to the air bubbles and float to the surface where they are skimmed off. The waste streams in question generally resemble the material skimmed from flotation devices; in fact one stream Dissolved Air Flotation Skimmings, is the result of application of the flotation process.
FREEZE CRYSTALLIZATION	Freeze crystallization has been developed and used for desalination of sea water. Although the process is generally considered as a demineralization technique, it is capable of removing organic materials from water as well. The waste streams in question are too high in SS to utilize this process. In addition, there has been only limited commercial development to date.

FREEZE DRYING	Freeze drying is a process in which water vapor is sublimed from material containing water in the frozen state in a high vacuum system. Energy consumption is higher for refrigeration and vacuum than alternative drying techniques.
SUSPENSION FREEZING	Suspension freezing is a process which removes suspended solids by agglomeration of the solids by freezing. At present there is limited commercial application of this process. The concentration of suspended solids in the waste stream is high and energy requirement for freezing will be great. Further developments in freeze processes for dewatering handicaps this process for the waste streams.
HIGH GRADIENT MAGNETIC SEPARATION	A process for removal of magnetic and para magnetic particles from liquid and slurry streams. The material requiring removal from the waste streams in question is not highly magnetic.
ION EXCHANGE	Ion exchange can be used for general and selective removal of metals and anions from aqueous waste streams. The treatment process requires removal of essentially all suspended solids before application of the process. As such, it is not suited for treatment of any of the waste streams in question (all are high in SS). In refining applications, the water would be returned to the wastewater treatment facility if the solids were removed.

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LIQUID ION EXCHANGE

Liquid ion exchange is a process used to concentrate salts in an organic solvent that is immiscible in water. Salts concentrate in the organic portion through phase migration. As in ion exchange, the presence of high amounts of suspended solids makes this process not applicable.

NEUTRALIZATION

Neutralization is the process of combining an acid or an alkali to adjust the pH to an acceptable level. Generally, pH of 6.0 to 9.0 is considered acceptable for effluent discharge. Adjustments in pH to facilitate precipitation of insolubles is considered part of the precipitation treatment process. One of the waste streams in question, neutralized HF alkylation sludge, can be considered the product of a neutralization reaction. Most of the refinery waste streams are in the pH range of 6 - 9 and hence need no further neutralization treatment.

CHEMICAL REDUCTION AND OXIDATION

Reduction-Oxidation reactions are those in which the oxidation state of one is raised while that of another is lowered. Chemical reduction or oxidation would have limited applicability to slurries and sludges unless it were possible to dilute them for treatment. It is best recommended for dilute acqueous streams and, in fact, the HF alkylation waste stream is treated by this method.

OZONATION

Ozonation is the oxidation of material by means of ozone. Ozonation is best suited for streams of aqueous or gaseous nature, and contain low levels of oxidizable materials. Sludges and slurries are unlikely candidates for ozonation.

PHOTOLYSIS

Photolysis is the process of breaking chemical bonds under the influence of light. While sunlight is capable of decomposing some materials, the reaction is sufficiently slow and the land areas involved would be prohibitive. For other radiation sources, the energy requirements would be enormous for the quantity of waste involved. There is no pilot or full scale application of a "pure" photochemical process to the decontamination of industrial waste streams and also technology for large-scale application of photolysis to waste is not developed.